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Scientific and Technical
Information Branch

SUMMARY

Airborne measurements of the launch vehicle effluent of the STS-2 launch on November 12, 1981, are presented. The second Space Shuttle (STS-2) was launched at 1010 EST from launch complex 39A (LC-39A) at Cape Canaveral, Florida. This set of measurements is one of many obtained by the National Aeronautics and Space Administration at selected rocket launches to study launch vehicle emissions and their impact on tropospheric air quality.

An instrumented light airplane measured the following: (1) particulate data in the form of a light scattering coefficient obtained from an integrating nephelometer; (2) particulate concentrations and mass concentrations obtained from a spectrometer probe; (3) gaseous HCl and total HCl concentrations obtained from a gas-filter-correlation instrument and a chemiluminescent instrument, respectively; and (4) outside-air temperature and dew-point temperature. In addition, time, altitude, and position of 31 data points (cloud passes) are presented.

These data contribute to an accumulating data base designed to characterize a typical Space Transportation System (STS) launch and assist in determining the resulting environmental effects.

INTRODUCTION

Since 1972, the National Aeronautics and Space Administration (NASA) has been conducting measurements of launch vehicle effluent (LVE) at selected NASA and Air Force launches for the purpose of investigating the environmental impact of launch vehicle emissions (mainly the exhaust of solid-propellent rocket motors) on tropospheric air quality. The LVE program is a multicenter activity involving the Langley Research Center (LaRC), the George C. Marshall Space Flight Center (MSFC), and the John F. Kennedy Space Center (KSC). Current program goals focus on obtaining a data base to assist in the determination of the environmental effects of Shuttle launches. The primary objective of this operation was to measure the concentrations of selected rocket exhaust products within and beneath the exhaust cloud formed during launch.

The results presented herein are from airborne measurements taken November 12, 1981, immediately following the second Space Shuttle (STS-2) launch. The launch time was 1010 EST (1510:10 GMT). The launch site was launch complex 39A (LC-39A) at Cape Canaveral, Florida.

This report is the second in a series of operational reports on monitoring Shuttle launch vehicle effluent in which the Langley Research Center participated. The first report (ref. 1), which was on the measurement results of the first Space Shuttle (STS-1), contains a comprehensive list of more than 70 references. These references are organized under the following categories: models and analytical studies, launch-site measurements, laboratory studies, instrumentation, and other. They constitute appendix A of reference 1 and serve as a reference summary for the LVE activities at the Langley Research Center.

SYMBOLS

Values are given in SI Units and, where considered useful, also in U.S. Customary Units. Measurements and calculations were made in U.S. Customary Units.

HCl(g)	hydrogen chloride, gaseous state
HCl(t)	hydrogen chloride, total (gaseous plus liquid aerosol)
L ±	launch ± minutes
T	outside-air temperature, °C
T_{dp}	dew-point temperature, °C
t_0	time at origin of data plot (e.g., see figs. 3, 4, and 6), referenced to GMT (or zulu Z)
β_{scat}	light scattering coefficient, m^{-1}

Abbreviations:

AFB	Air Force Base
EST	eastern standard time
GFC	gas-filter-correlation instrument
GMT	Greenwich mean time
GOES	Geostationary Operational Environmental Satellite
KSC	John F. Kennedy Space Center
LaRC	Langley Research Center
LC	launch complex
LORAN-C	long-range navigation; C represents third generation
LVE	launch vehicle effluent
MSFC	George C. Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
STS	Space Transportation System
VHF	very high frequency
VOR	VHF omnidirectional range

OPERATIONAL DATA

Airborne Platform and Sensor Descriptions

The airplane used for airborne measurements was a light, twin-engine Cessna 402 which was chartered and outfitted by the Langley Research Center. The airplane has a flight speed of 135 knots (maximum), ascent and descent rates of less than 150 m/min, and a flight endurance of 2 1/2 hr.

For the LVE monitoring effort of the STS-2, the primary airplane instrumentation systems were as follows: a gas-filter-correlation (GFC) instrument measuring gaseous HCl, a chemiluminescent detector measuring total HCl, an optical-array cloud-droplet spectrometer probe measuring particulates in the diameter range from 20 to 300 μm, and an integrating nephelometer recording the light scattering coefficient of the cloud particles. In addition, airspeed, outside-air temperature, dew-point temperature, heading, altitude, time, and position were recorded. The flight crew consisted of the pilot, a flight coordinator, and two instrument operators.

Data were recorded as received on strip-chart recorders and printers for a "quick-look" evaluation and were also collected simultaneously on magnetic tape for further data reduction.

Sampling Scenario

At launch minus 20 min (L - 20 min), the Cessna airplane took off from Patrick Air Force Base, Florida, and was positioned in a holding pattern at 762.0 m (2500 ft) approximately 12.9 km (8 miles) south of launch complex 39A, which was directly over the skid strip. At 2 min after launch (L + 2 min), the Cessna was released from the holding pattern and, because of a favorable wind blowing the cloud southward, was able to intercept the launch cloud in a record time of 5 min 10 sec after launch (1015:12 EST).

A total of 31 passes (24 through the cloud and 7 below the cloud) were made during the next 1 hr 45 min at altitudes between 762.0 m (2500 ft) and 1481 m (4860 ft) as shown in table I. All "through" passes were aimed at the cloud center, and all "below" passes were aimed at a point 100 m (estimated) below the bottom of the cloud. The cloud track during the sampling period is shown in figure 1. The flight path of the sampling airplane is shown in figure 2.

Data were recorded as received on strip-chart recorders and printers for a "quick-look" evaluation and were also collected simultaneously on magnetic tape for further data reduction. The magnetic-tape recorder stopped between pass 11 and pass 12 because of a spurious ray of sunlight which triggered the end-of-tape sensor, thereby cutting the magnetic-tape recorder off. This incident occurred simultaneously with a steep climb/turn maneuver of the airplane. Because of the recorder stoppage, no outside-air temperature, dew-point, or β_{scat} digital data were recorded for passes 12 through 31.

MEASUREMENT RESULTS AND ANALYSIS

Airborne-Data Analysis

Of the 1 hr 45 min during which the 31 passes were made, a total of 31.54 min were spent in the cloud. The average sample was 61 sec long. The shortest sample was pass 1 (16 sec), and the longest sample was pass 25 (2 min 5 sec). Pass 1 was a short sample because the cloud was essentially still a column. Pass 25 approximated the end of the cloud as one continuum, beyond which it became fragmented.

Particulates

Plots of β_{scat} for passes 1 through 11 (after which the recorder stopped) are shown as figure 3. Outside-air temperature and dew-point temperature for passes 1 through 11 are plotted together and shown as figure 4.

In-cloud β_{scat} values, as measured with the integrating nephelometer, range from 10^{-3} m^{-1} early in the cloud to 10^{-4} m^{-1} after the cloud dispersed. These β_{scat} values are slightly less than, but of the same order as, those measured in the STS-1 exhaust cloud. Measurements below the cloud show a value of β_{scat} of 9×10^{-4} m^{-1} for the first pass at L + 5 min, but the values drop off rapidly as time increases. (Pass 1, although listed as "below" the cloud, should be considered in reality to be a pass through the column since no cloud separation had occurred. The penetration point was selected based on a bulge in the column which appeared to be the start of a cloud formation. Hence, penetration approximately 100 m below the bulge constituted the first pass.) The small particles (between 0.2- and 1-μm diameter) are the major contributions to the β_{scat} values and the larger particles have very little effect. These small particles therefore remained in the cloud, but dispersed, throughout the sampling period.

Spectrometer-Probe Measurements

The spectrometer probe, often called a Knollenberg Probe, provided measurements of the distribution of larger particles (ranging in diameter from 20 to 300 μm) resulting from the STS-2 launch. The data taken both in and under the Shuttle exhaust cloud as a function of time were classified by size and were counted in 15 size intervals by the particle measuring system. These data are presented in tables II to IV.

The tabulated results of the mean-number concentration in units of particles per cubic centimeter for each pass (for passes 1 through 13) "through" or "below" the cloud are listed by channel number (and hence size, see table IV) in table II. There were no measurable particles in this size range after pass 13. The corresponding mass-concentration values (in units of micrograms per cubic meter) are listed in table III. Table IV contains the data relating instrument channel number to particle size.

Histogram plots of the particle-number concentration (upper plot) and the corresponding mass concentration (lower plot) for passes 1 through 13 are shown as figure 5. These data indicate that the amount of suspended particulate material with a diameter larger than 20 μm decreases rapidly after launch. This decrease is probably due mainly to the large particles dropping out of the cloud.

HCl Measurements from Chemiluminescent Instrument

The peak values of total HCl for each of the 31 passes are presented in table V (column 4). Plots of total HCl for each pass are shown as figure 6. Peak values of total HCl taken from the strip-chart recorder range from 4.8 ppm on pass 5 to 0.17 ppm on pass 30 for "through-cloud passes" and from 3.0 ppm on pass 3 to 0.36 ppm on pass 7 below the cloud.

HCl Measurements from Gas-Filter-Correlation Instrument

The measured values of gaseous HCl for each pass are shown in table V (column 5). Peak values of gaseous HCl taken from the strip-chart recorder for passes 1 through 31 ranged from 1.68 ppm on pass 5 to 0.25 ppm on pass 20 for through-cloud passes and were 0.63 ppm on passes 1 and 3, which were the only below-cloud passes where the concentration was within the detectable limit of the GFC instrument.

GOES Satellite Surveillance

Satellite surveillance (GOES East) in a rapid-scan mode was requested during the anticipated launch time to see if the STS-2 launch cloud was detectable. The GOES image was furnished through the courtesy of the National Earth Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA). The picture obtained, which was reproduced and shown as figure 7, was taken at 1011:30 EST (1511:30 GMT) on November 12, 1981. The launch vehicle cloud trail is clearly shown, but information relative to the ground cloud (below an altitude of 1524 m (5000 ft)) and its behavior is not readily discernible from the 0.8-km (1/2-mile) resolution format.

Should a future Shuttle launch be coordinated with a Landsat satellite overpass, it would seem that satellite surveillance would provide an additional dimension for monitoring launch vehicle clouds.

SUMMARY OF RESULTS

The second Space Shuttle (STS-2) was launched November 12, 1981, at 1010 EST from launch complex 39A at Cape Canaveral, Florida. A Cessna 402 twin-engine airplane, which was instrumented by the Langley Research Center, monitored the launch vehicle exhaust cloud. Measurements of launch vehicle effluent were made during a series of 31 passes both under and through the exhaust cloud in the 1 hr 45 min immediately following the launch. The following results were obtained:

1. Particulate data from an integrating nephelometer are presented in terms of a light scattering coefficient β_{scat} for passes 1 through 11. Also presented for these passes are outside-air temperature and dew-point temperature.

2. Particulate data from the spectrometer probe are presented as mean concentration in particles per cubic centimeter and as mass concentration per channel in micrograms per cubic meter.

3. Measurements of gaseous HCl and total HCl as recorded by the gas-filter-correlation instrument and the chemiluminescent instrument, respectively, are presented for passes 1 through 31. In addition, the time, altitude, and position of each cloud pass are presented.

4. These measurements agree with similar measurements made during the launch of the first Space Shuttle (STS-1) on April 12, 1981. The measurements provide, in

part, the data and an assessment of the environmental effects of the STS-2 launch. It is hoped that the results contribute to an accumulating data base which will ultimately characterize a typical Space Transportation System (STS) launch.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
January 24, 1984

REFERENCE

1. Gregory, Gerald L.; Woods, David C.; and Sebacher, Daniel I.: Airborne Measurements of Launch Vehicle Effluent - Launch of Space Shuttle (STS-1) on April 12, 1981. NASA TP-2090, 1983.

TABLE I.- AIRBORNE DATA OF STS-2 LAUNCH ON NOVEMBER 12, 1981

[Cessna 402 data]

Pass	Airplane position with respect to cloud	Time after launch, min	Altitude, m	Airplane geographical position (a)	LORAN-C navigation data	
					Latitude, North	Longitude, West
1	Below	L + 5	762.0	37.1 km N	28°35.63'	80°35.65'
2	Through	L + 7	1036.3	37.1 km N		
3	Below	L + 10	883.9	090/69.5 km		
4	Below	L + 12	701.0	090/69.5 km		
5	Through	L + 16	1066.8	094/68.6 km		
6	Below	L + 19	762.0	30.6 km N		
7	Below	L + 21	731.5	098/67.6 km	28°29.95'	80°37.35'
8	Through	L + 25	1005.8	098/67.6 km	28°29.95'	80°37.35'
9	Through	L + 27	1005.8	100/66.7 km	28°29.15'	80°39.86'
10	Below	L + 31	767.0		28°28.85'	80°38.45'
11	Through	L + 33	914.4	103/64.9 km	28°26.96'	80°39.96'
12	Through	L + 36	914.4		28°26.11'	80°41.00'
13	Through		914.4	106/66.7 km	28°26.75'	80°40.47'
14	Through	L + 40	1005.8	106/64.9 km	28°26.76'	80°41.55'
15	Through	L + 42	1005.8	106/64.9 km	28°25.84'	80°40.93'
16	Through	L + 46	1005.8	106/64.9 km	28°25.53'	80°42.22'
17	Through	L + 48	1005.8	108/64.9 km	28°24.99'	80°41.22'
18	Through	L + 51	1005.8	106/62.1 km	28°24.95'	80°39.69'
19	Through		1005.8	106/62.1 km	28°24.37'	80°41.26'
20	Through	L + 56	1005.8	108/64.9 km	28°23.16'	80°42.02'
21	Through	L + 60	1188.7	112/68.6 km	28°21.25'	80°38.13'
22	Through	L + 63	1188.7		28°20.77'	80°40.81'
23	Through	L + 67	1188.7	115/68.6 km	28°19.88'	80°40.48'
24	Below	L + 76	1188.7	103/71.3 km	28°24.17'	80°36.05'
25	Through	L + 84	1463.0	115/76.0 km	28°18.40'	80°35.69'
26	Through	L + 90	1481.3	121/73.2 km	28°13.30'	80°41.02'
27	Through	L + 92	1481.3	1.8 km W	28°14.47'	80°38.65'
28	Through	L + 94	1481.3	121/74.1 km	28°13.03'	80°38.84'
29	Through	L + 97	1481.3	4.6 km W	28°13.32'	80°39.04'
30	Through	L + 99	1481.3		28°12.91'	80°40.18'
31	Through	L + 105	1158.2	122/68.6 km	28°12.58'	80°44.07'

[a]Data for the airplane geographical position are entered in one of two ways as given by the pilot: (1) When a distance is given such as 37.1 km N, the data point locates the airplane with respect to Patrick Air Force Base; and (2) when a VOR reading, angle (radial)/distance, is given, the data point locates the airplane with respect to the Orlando International Airport. For example, 090/69.5 km means directly out the 90° radial from the Orlando Airport, a distance of 69.5 km.

TABLE II.- PARTICLE-NUMBER CONCENTRATION IN STS-2 EXHAUST CLOUD

Channel (size range)	Particle-number concentration, cm^{-3}, in each channel for -												
	Pass 1 (a, b)	Pass 2	Pass 3 (a)	Pass 4 (a)	Pass 5	Pass 6 (a)	Pass 7 (a)	Pass 8	Pass 9 (c)	Pass 10 (a)	Pass 11	Pass 12	Pass 13
1	0	0	0	0	0	0	1.2×10^{-2}	0		0	5.8×10^{-3}	5.8×10^{-3}	0
2	9.3×10^{-3}	0	0	0	0	0	0	2.3×10^{-3}		0	1.6×10^{-3}	7.0×10^{-3}	1.6×10^{-3}
3	1.4×10^{-2}	5.4×10^{-3}	0	0	1.1×10^{-3}	0	0	1.1×10^{-3}		0	3.5×10^{-3}	1.1×10^{-3}	1.9×10^{-3}
4	5.3×10^{-3}	5.9×10^{-4}	0	0	5.9×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	1.5×10^{-4}		1.5×10^{-4}	1.5×10^{-4}	1.0×10^{-3}	1.5×10^{-4}
5	2.9×10^{-3}	4.1×10^{-4}	0	0	1.2×10^{-3}	2.0×10^{-4}	0	0		0	0	1.0×10^{-4}	2.0×10^{-4}
6	1.2×10^{-3}	3.0×10^{-4}	3.0×10^{-4}	0	6.1×10^{-4}	0	1.5×10^{-4}	0		4.6×10^{-4}	0	0	0
7	1.7×10^{-3}	7.2×10^{-4}	2.4×10^{-4}	0	4.8×10^{-4}	1.2×10^{-4}	3.6×10^{-4}	0		6.0×10^{-5}	0	0	0
8	1.7×10^{-3}	1.1×10^{-3}	8.6×10^{-4}	0	0	2.1×10^{-4}	2.1×10^{-4}	0		0	0	0	0
9	6.9×10^{-4}	4.6×10^{-4}	0	0	0	2.3×10^{-4}	2.3×10^{-4}	0		0	0	0	0
10	2.5×10^{-4}	4.9×10^{-4}	0	0	0	0	1.2×10^{-4}	0		0	0	0	0
11	2.7×10^{-4}	2.7×10^{-4}	2.7×10^{-4}	2.7×10^{-4}	0	1.3×10^{-4}	0	0		0	0	0	0
12	2.9×10^{-4}	5.8×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	0	0	1.5×10^{-4}	0		0	0	0	0
13	6.4×10^{-4}	9.6×10^{-4}	0	0	0	0	0			0	0	0	0
14	0	3.6×10^{-4}	0	0	0	0	0			0	0	0	0
15	4.0×10^{-4}	0	0	0	0	0	0			0	0	0	0

[a]Pass below the cloud.

[b]Pass 1, although listed as "below" the cloud, should be considered in reality to be a pass through the column since no cloud separation had occurred. The penetration point was selected based on a bulge in the column which appeared to be the start of a cloud formation. Hence, penetration approximately 100 m below the bulge constituted the first pass.

[c]The instrument was not in the sensing mode in pass 9.

TABLE III.- MASS CONCENTRATION IN STS-2 EXHAUST CLOUD

Channel (size range)	Mass concentration, μgm^{-3}, in each channel for -												
	Pass 1 (a, b)	Pass 2	Pass 3 (a)	Pass 4 (a)	Pass 5	Pass 6 (a)	Pass 7 (a)	Pass 8	Pass 9 (c)	Pass 10 (a)	Pass 11	Pass 12	Pass 13
1	0	0	0	0	0	0	3.3×10^2	0		0	1.6×10^2	1.6×10^2	0
2	1.2×10^3	0	0	0	0	0	0	3.1×10^2		0	2.0×10^2	9.2×10^2	2.0×10^2
3	5.1×10^3	2.0×10^3	0	0	3.9×10^2	0	0	3.9×10^2		0	1.3×10^3	3.9×10^2	6.8×10^2
4	4.1×10^3	4.5×10^2	0	0	4.5×10^2	2.3×10^2	2.3×10^2	1.1×10^2		1.1×10^2	1.1×10^2	7.9×10^3	1.1×10^2
5	4.0×10^3	5.7×10^2	0	0	1.7×10^3	2.8×10^2	0	0		0	0	1.4×10^2	2.8×10^2
6	2.8×10^3	7.0×10^2	7.0×10^2	0	1.4×10^3	0	3.5×10^2	0		1.0×10^3	0	0	0
7	2.4×10^3	5.6×10^3	8.5×10^2	0	1.7×10^3	4.3×10^2	1.3×10^3	0		2.1×10^2	0	0	0
8	8.8×10^3	5.5×10^3	4.4×10^3	0	0	1.1×10^2	1.1×10^3	0		0	0	0	0
9	5.0×10^3	3.3×10^3	0	0	0	1.7×10^3	1.7×10^3	0		0	0	0	0
10	2.4×10^3	4.8×10^3	0	0	0	0	1.2×10^3	0		0	0	0	0
11	3.4×10^3	3.4×10^3	3.4×10^3	3.4×10^3	0	1.7×10^3	0	0		0	0	0	0
12	4.8×10^3	9.6×10^3	4.8×10^3	4.8×10^3	0	0	2.4×10^3	0		0	0	0	0
13	1.3×10^4	3.0×10^4	0	0	0	0	0	0		0	0	0	0
14	0	9.1×10^3	0	0	0	0	0	0		0	0	0	0
15	1.3×10^4	0	0	0	0	0	0	0		0	0	0	0

[a]Pass below the cloud.

[b]Pass 1, although listed as "below" the cloud, should be considered in reality to be a pass through the column since no cloud separation had occurred. The penetration point was selected based on a bulge in the column which appeared to be the start of a cloud formation. Hence, penetration approximately 100 m below the bulge constituted the first pass.

[c]The instrument was not in the sensing mode in pass 9.

TABLE IV.- SIZE CHANNEL FOR CLOUD-DROPLET PROBE

Channel (size range)	Diameter, μm
1	20
2	40
3	60
4	80
5	100
6	120
7	140
8	160
9	180
10	200
11	220
12	240
13	260
14	280
15	300

TABLE V.- HCl MEASUREMENTS FOR PASSES 1 THROUGH 31

[Data obtained by GFC and chemiluminescent instruments]

Pass	Airplane position with respect to cloud	Time after launch, min	Column 4	Column 5
			Peak values of HCl(t) obtained by chemiluminescent instrument, ppm	Peak values of HCl(g) obtained by GFC instrument, ppm
1	Below	L + 5	4.6	0.63
2	Through	L + 7	4.8	1.26
3	Below	L + 10	3.0	.63
4	Below	L + 12	1.3	
5	Through	L + 16	4.8	1.68
6	Below	L + 19	.36	
7	Below	L + 21	.36	
8	Through	L + 25	2.9	1.47
9	Through	L + 27	3.2	1.26
10	Below	L + 31		
11	Through	L + 33	1.3	.42
12	Through	L + 36	2.0	.38
13	Through			
14	Through	L + 40	2.1	.84
15	Through	L + 42	1.7	.80
16	Through	L + 46	1.4	.80
17	Through	L + 48	1.5	.84
18	Through	L + 51	1.1	.76
19	Through			
20	Through	L + 56	.2	.25
21	Through	L + 60	1.04	.74
22	Through	L + 63	1.20	.84
23	Through	L + 67	.80	.63
24	Below	L + 76		
25	Through	L + 84	.36	.38
26	Through	L + 90	.47	.32
27	Through	L + 92	.30	
28	Through	L + 94	.36	
29	Through	L + 97	.62	
30	Through	L + 99	.17	
31	Through	L + 105	.17	

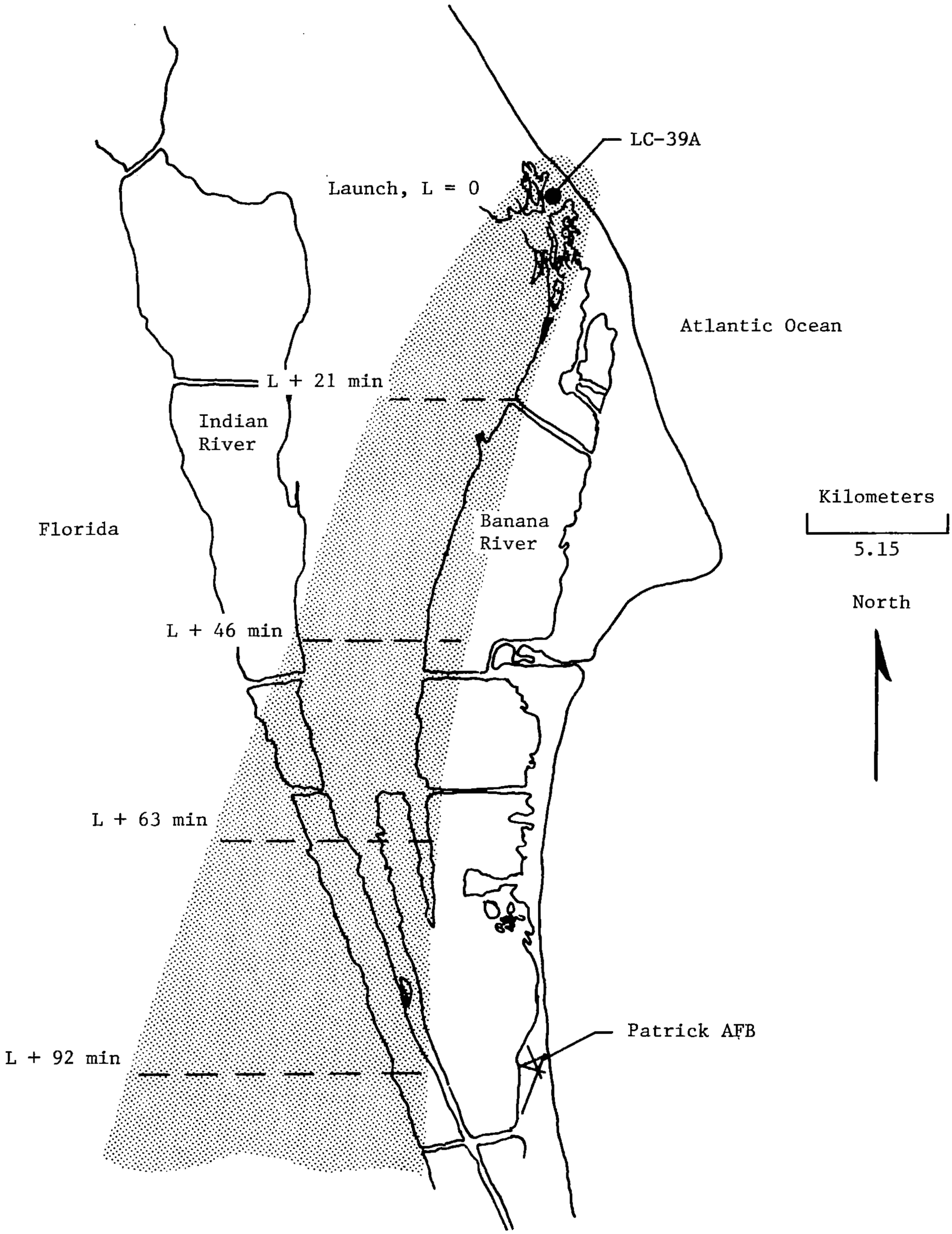


Figure 1.- Cloud track during sampling period over Cape Canaveral, Florida.

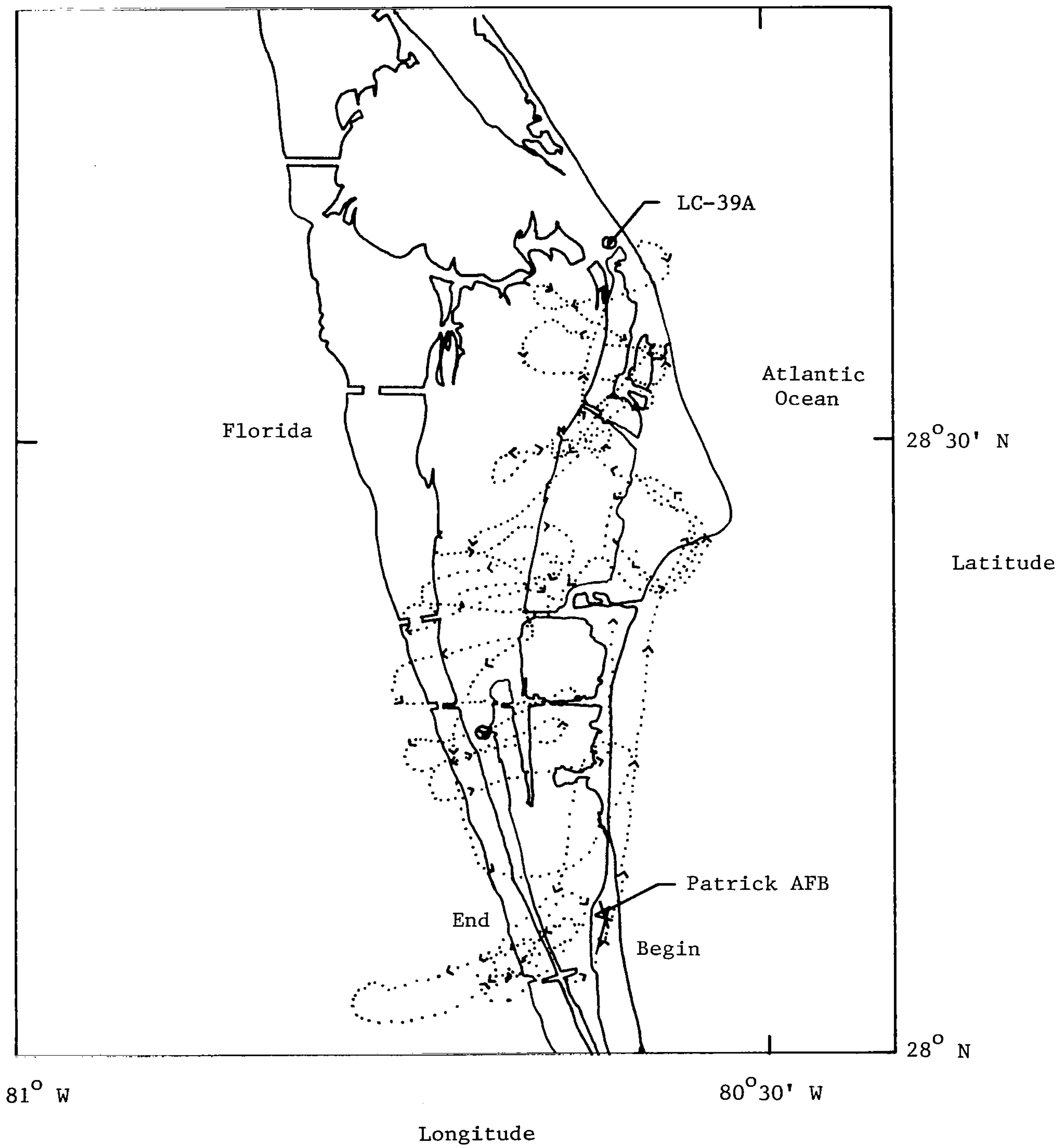
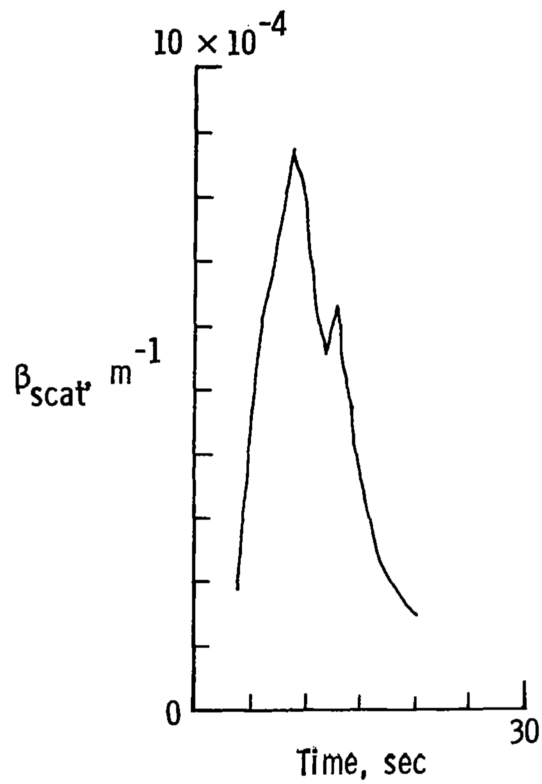
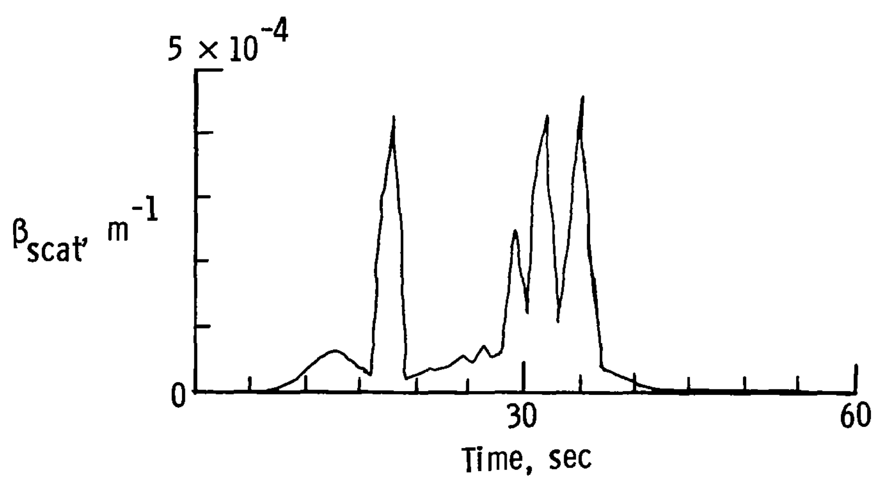


Figure 2.- Flight path of STS-2 sampling airplane.

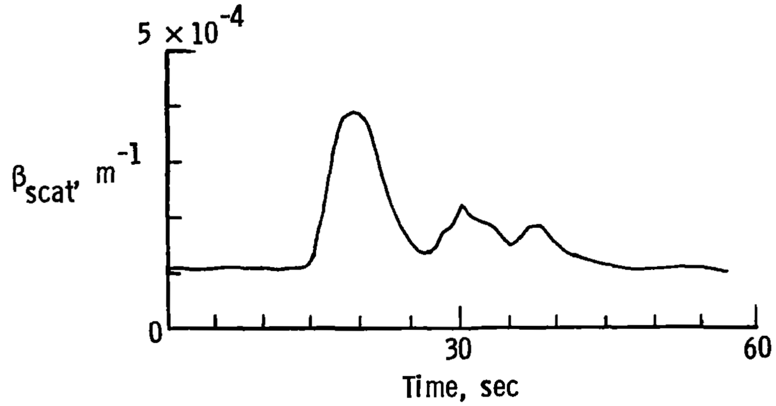


(a) Pass 1; t_0 = 151 500 Z.

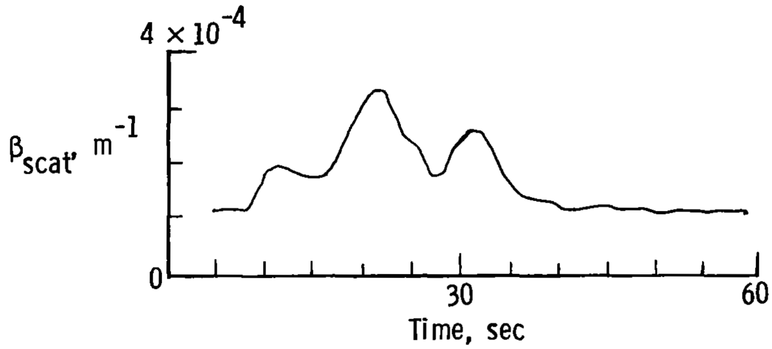


(b) Pass 2; t_0 = 151 730 Z.

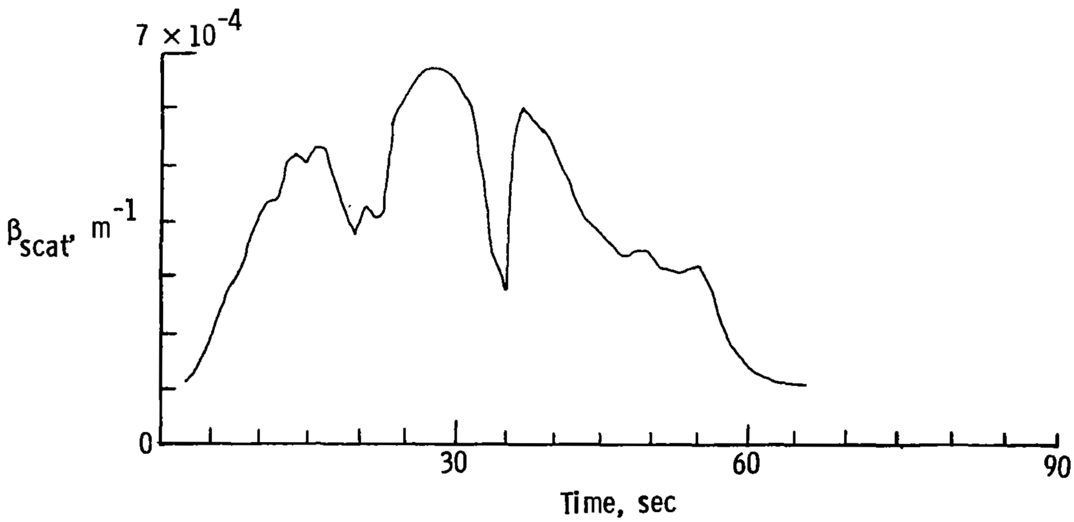
Figure 3.- Light scattering coefficient β_{scat} as measured by integrating nephelometer for passes 1 through 11. The times for t_0 may not agree from instrument to instrument for the same pass.



(c) Pass 3; t_0 = 152 030 Z.

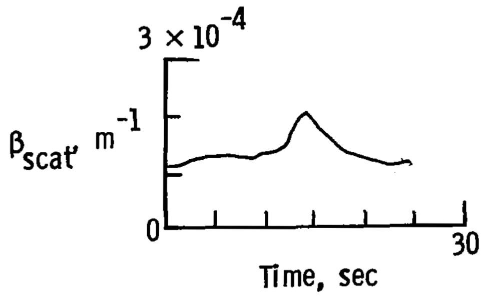


(d) Pass 4; t_0 = 152 230 Z.

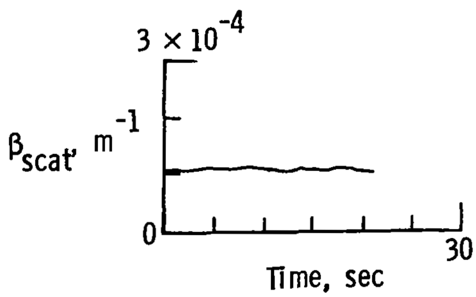


(e) Pass 5; t_0 = 152 555 Z.

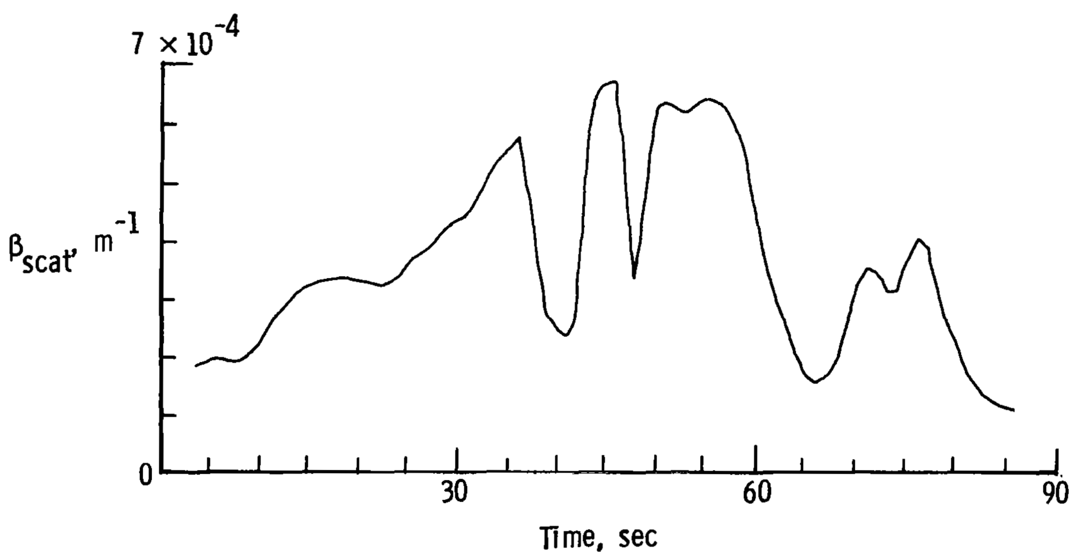
Figure 3.- Continued.



(f) Pass 6; t_0 = 152 920 Z.

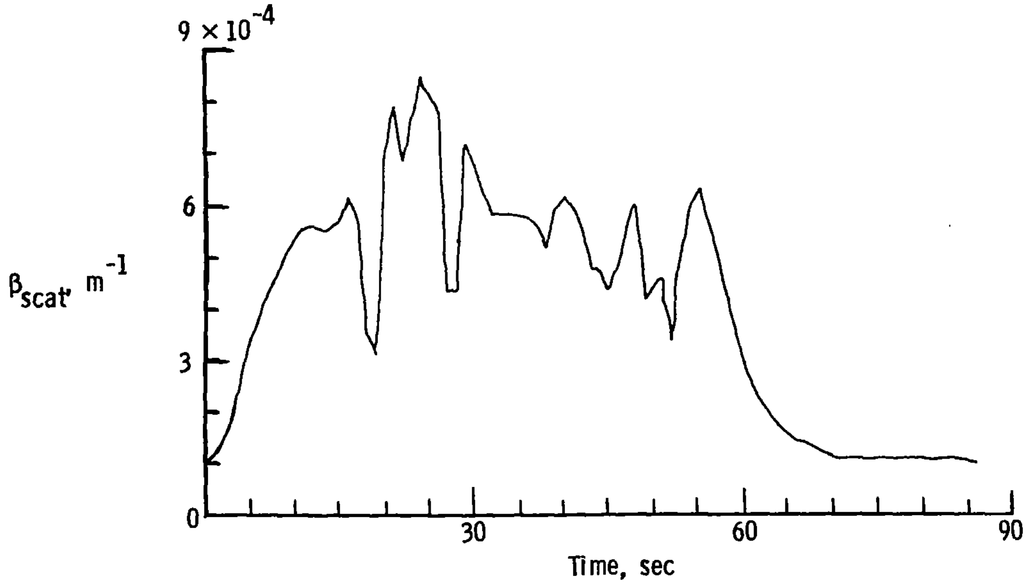


(g) Pass 7; t_0 = 153 130 Z.

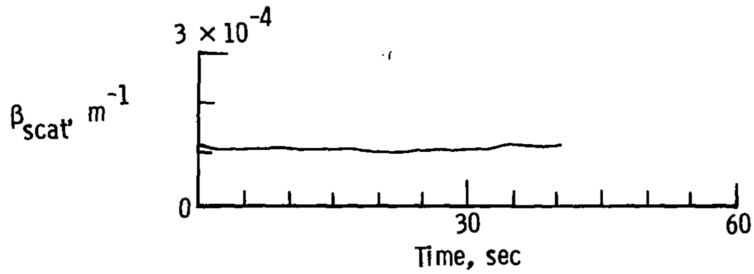


(h) Pass 8; t_0 = 153 500 Z.

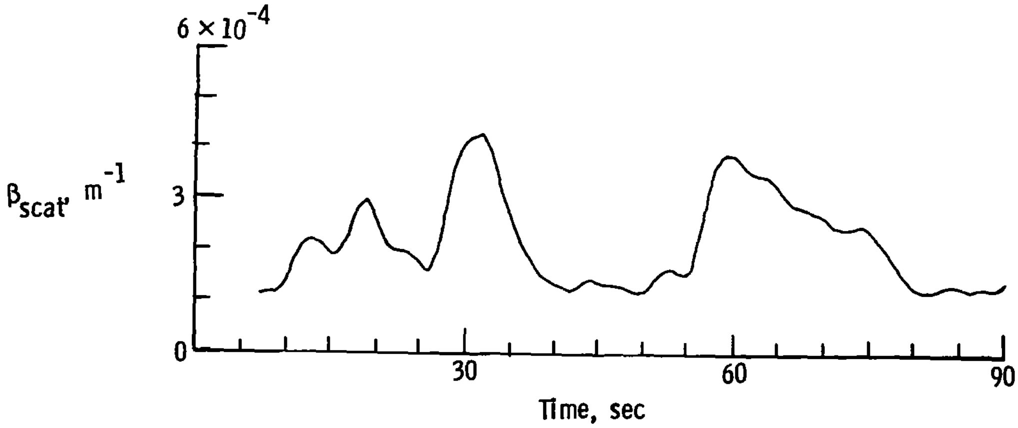
Figure 3.- Continued.



(i) Pass 9; t_0 = 153 730 Z.

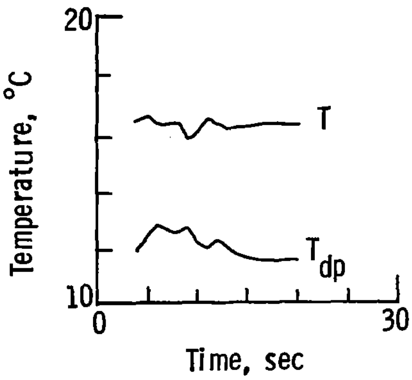


(j) Pass 10; t_0 = 154 100 Z.

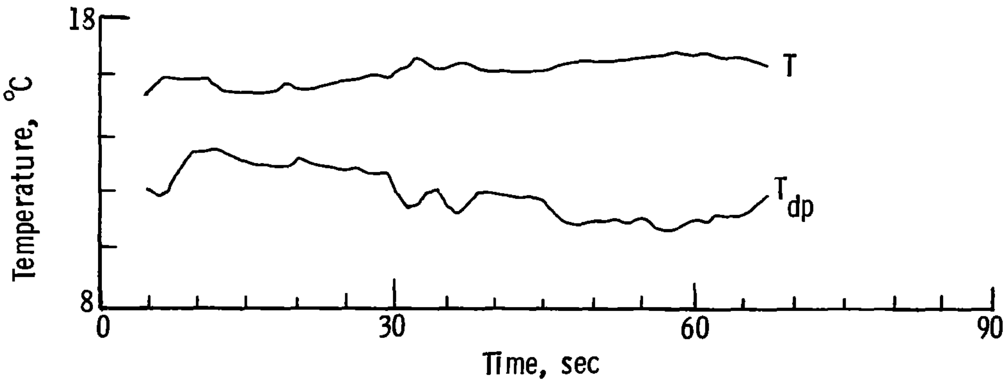


(k) Pass 11; t_0 = 154 300 Z.

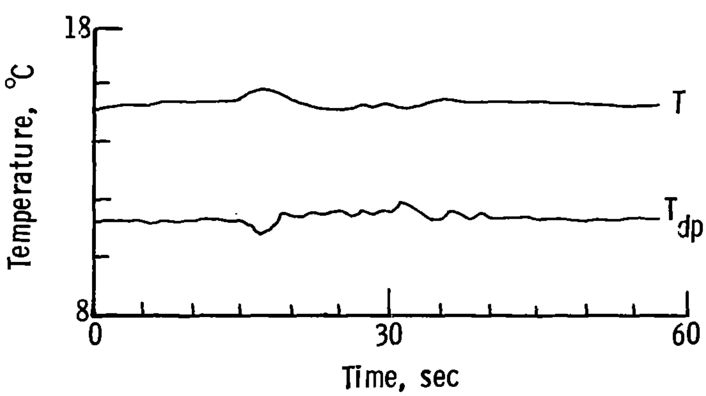
Figure 3.- Concluded.



(a) Pass 1; t_0 = 151 500 Z.

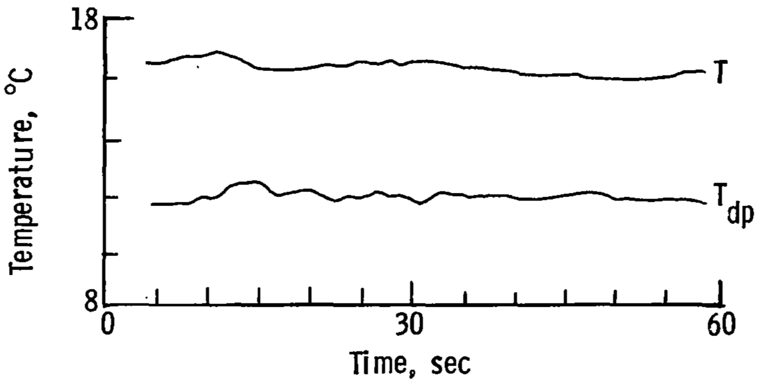


(b) Pass 2; t_0 = 151 730 Z.

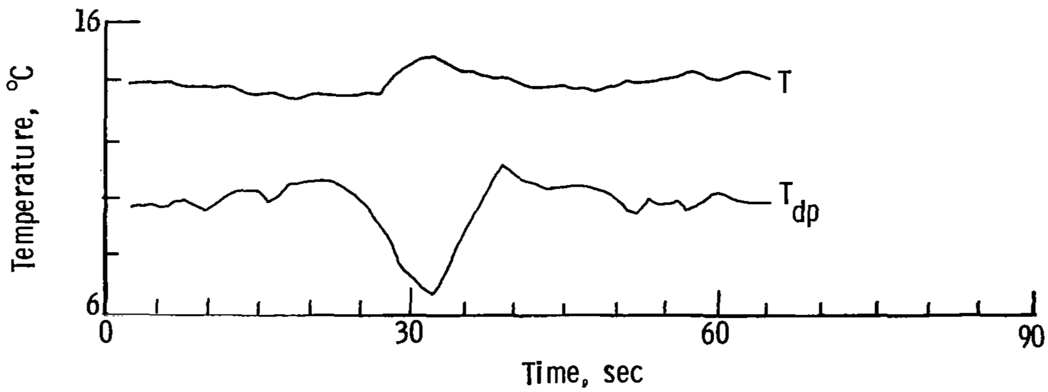


(c) Pass 3; t_0 = 152 030 Z.

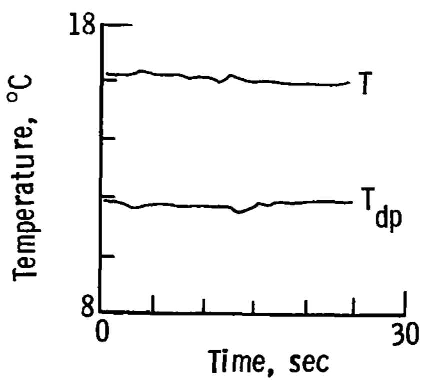
Figure 4.- Measurements for outside-air temperature T and dew-point temperature T_{dp} for passes 1 through 11. The times for t_0 may not agree from instrument to instrument for the same pass.



(d) Pass 4; t_0 = 152 230 Z.

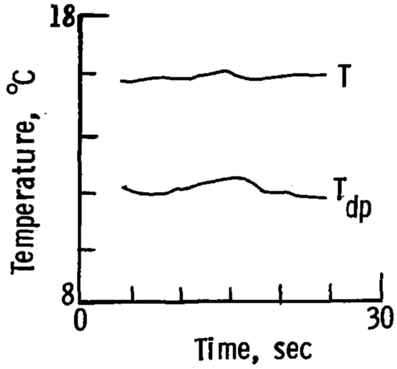


(e) Pass 5; t_0 = 152 555 Z.

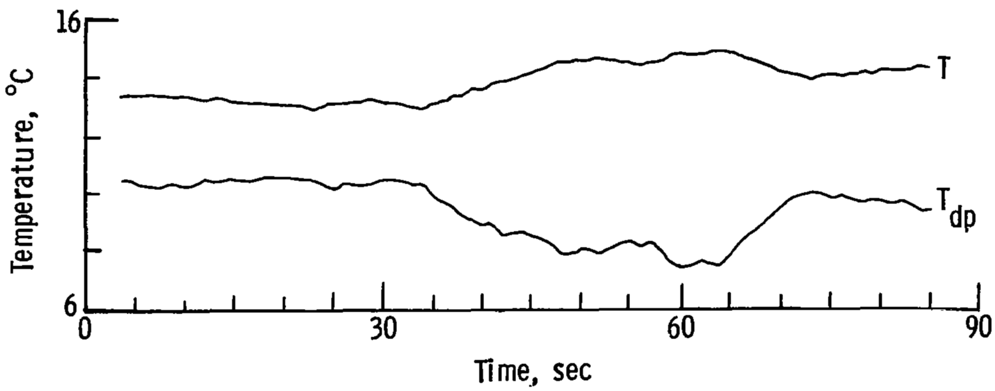


(f) Pass 6; t_0 = 152 920 Z.

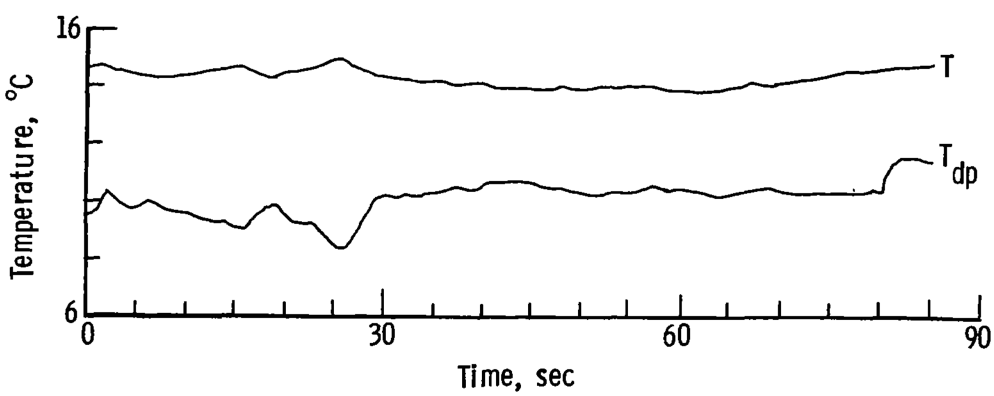
Figure 4.- Continued.



(g) Pass 7; t_0 = 153 125 Z.

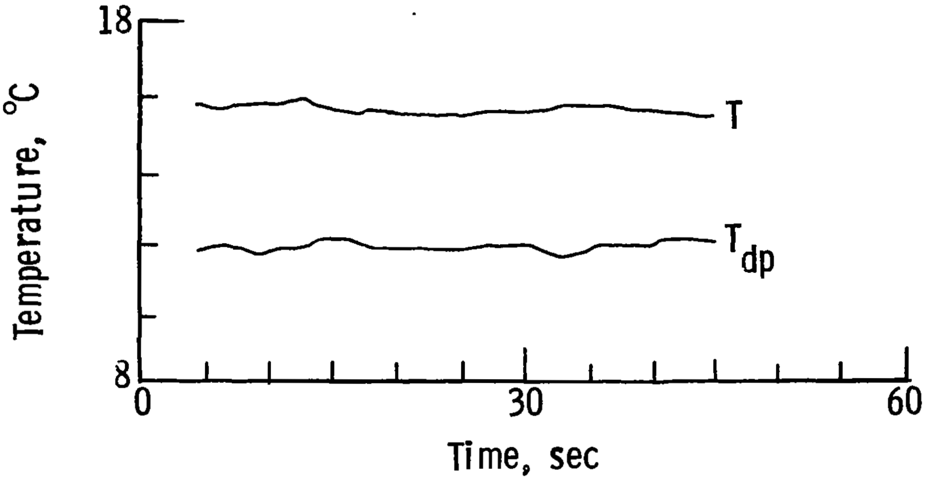


(h) Pass 8; t_0 = 153 500 Z.

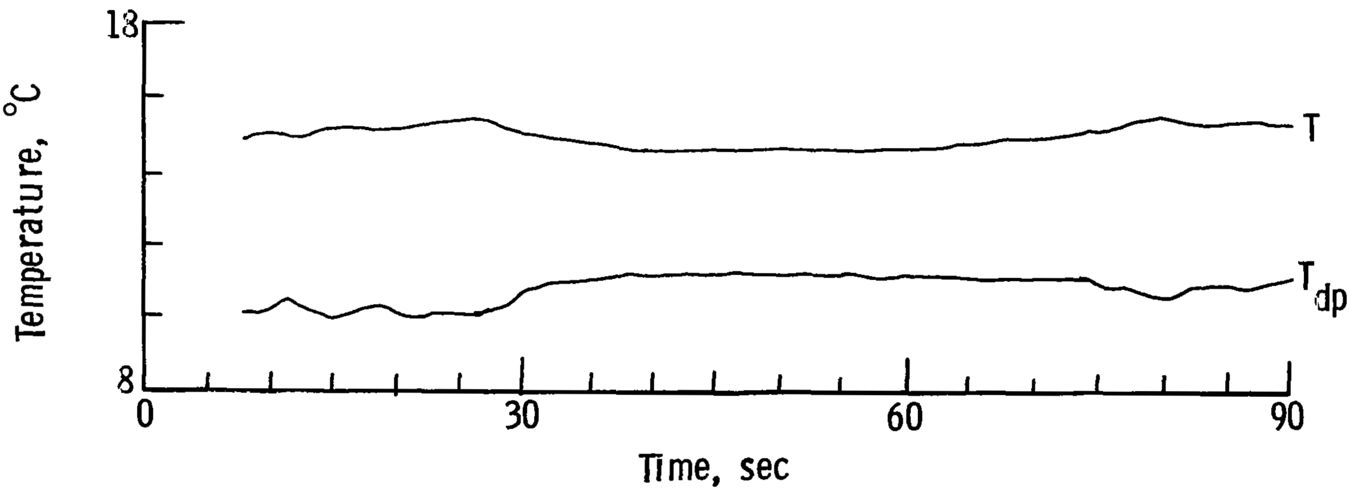


(i) Pass 9; t_0 = 153 730 Z.

Figure 4.- Continued.

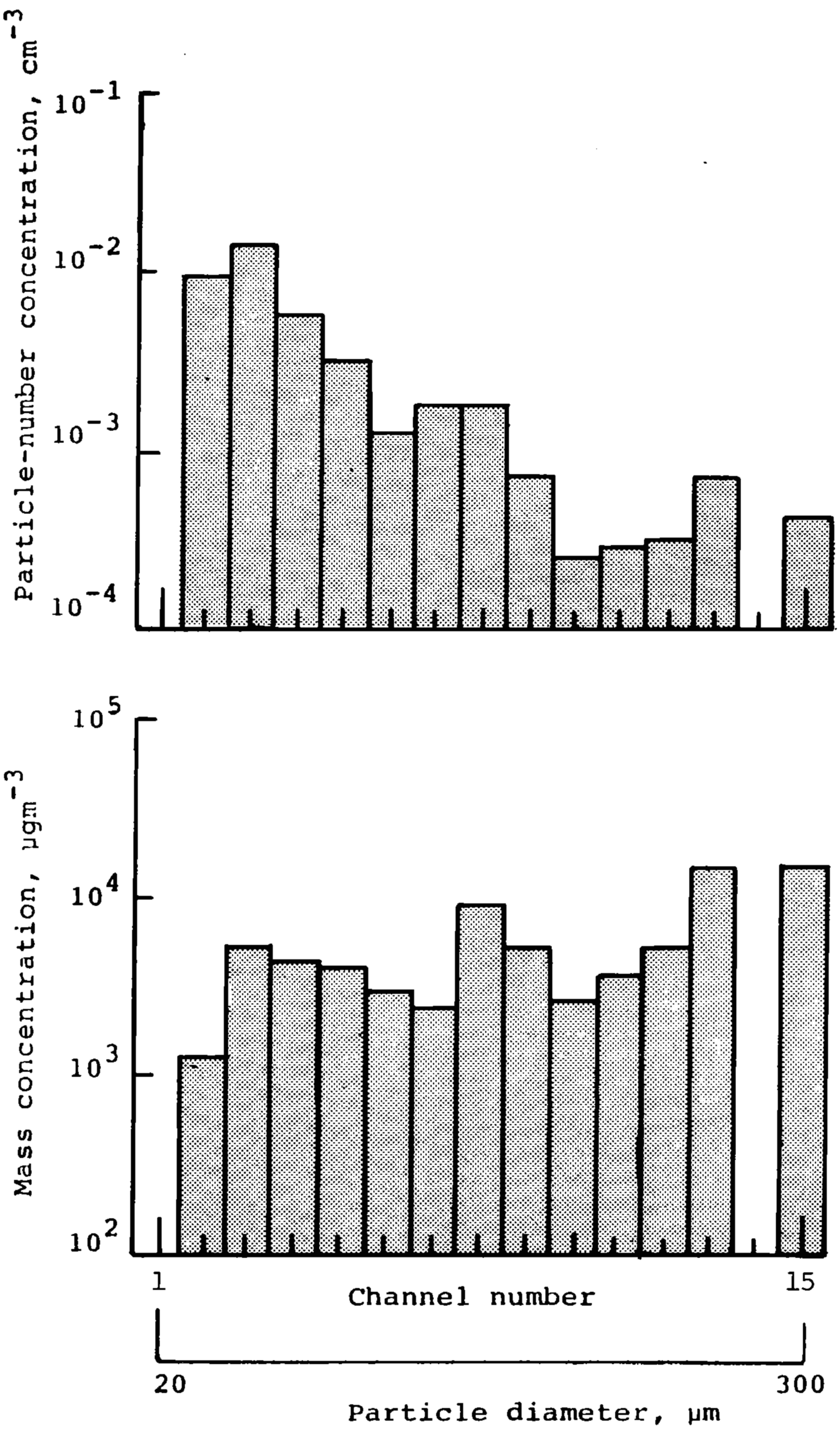


(j) Pass 10; t_0 = 154 055 Z.



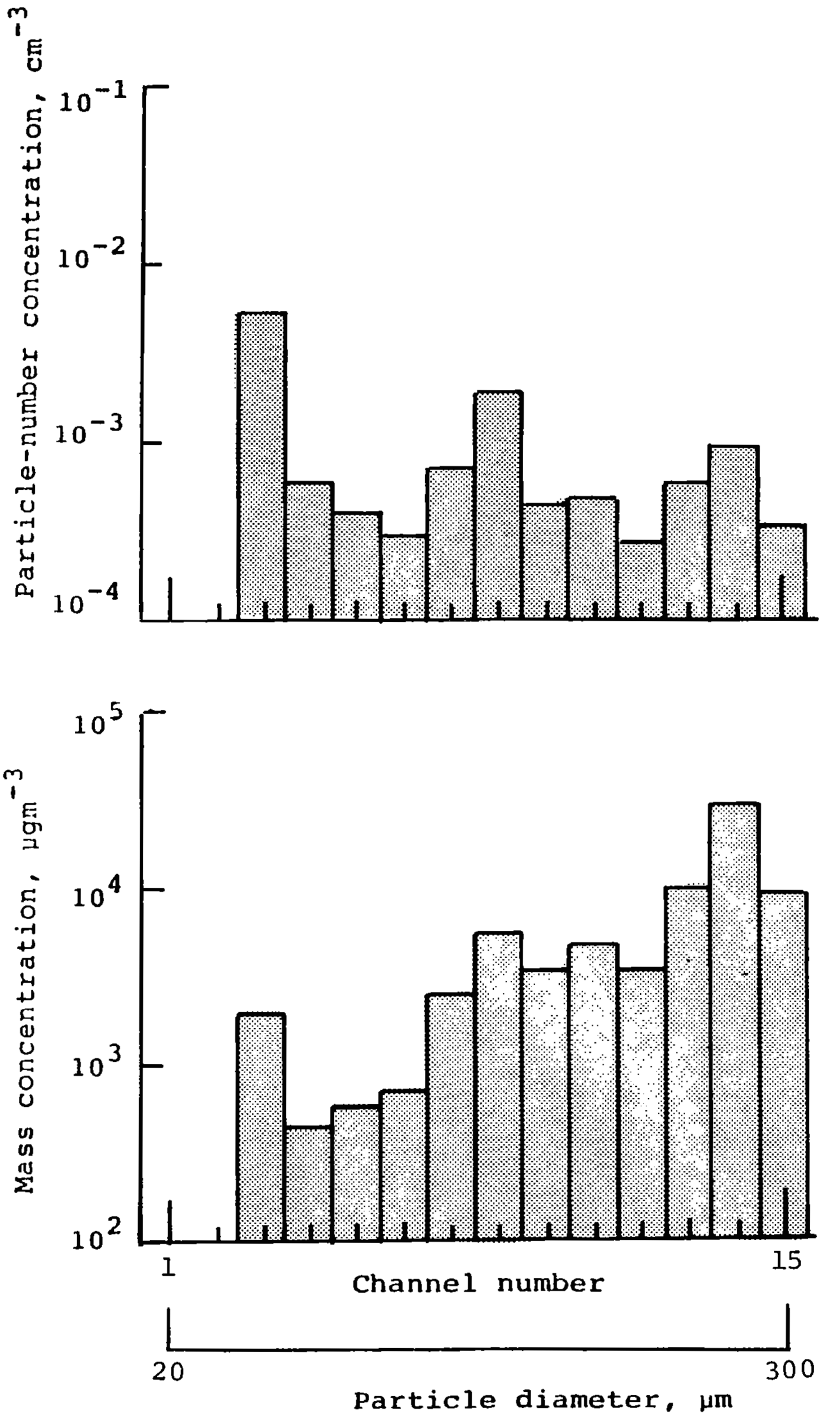
(k) Pass 11; t_0 = 154 300 Z.

Figure 4.- Concluded.



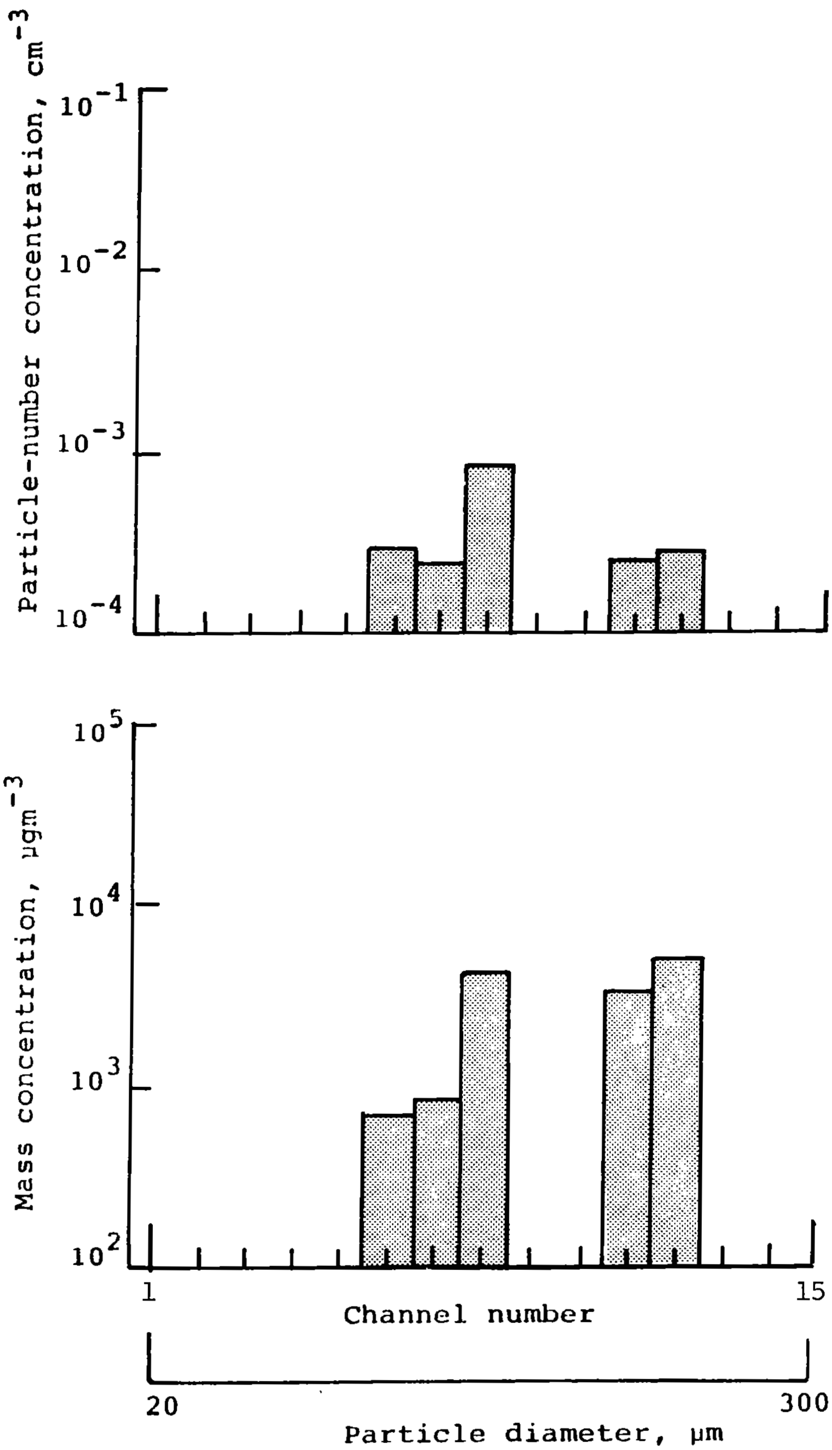
(a) Pass 1.

Figure 5.- Particle-number concentration and mass concentration in each channel (size range) for passes 1 through 13.



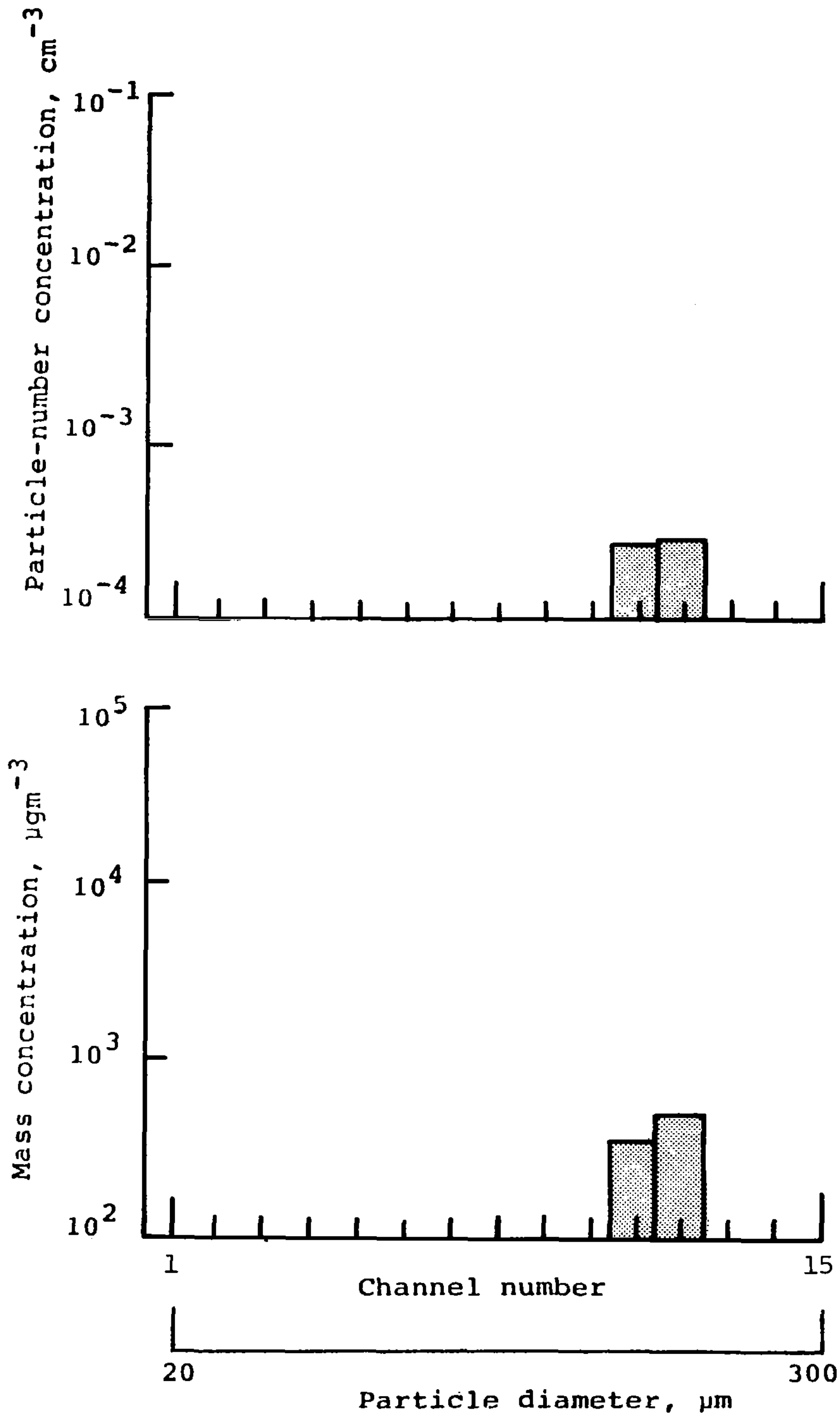
(b) Pass 2.

Figure 5.- Continued.



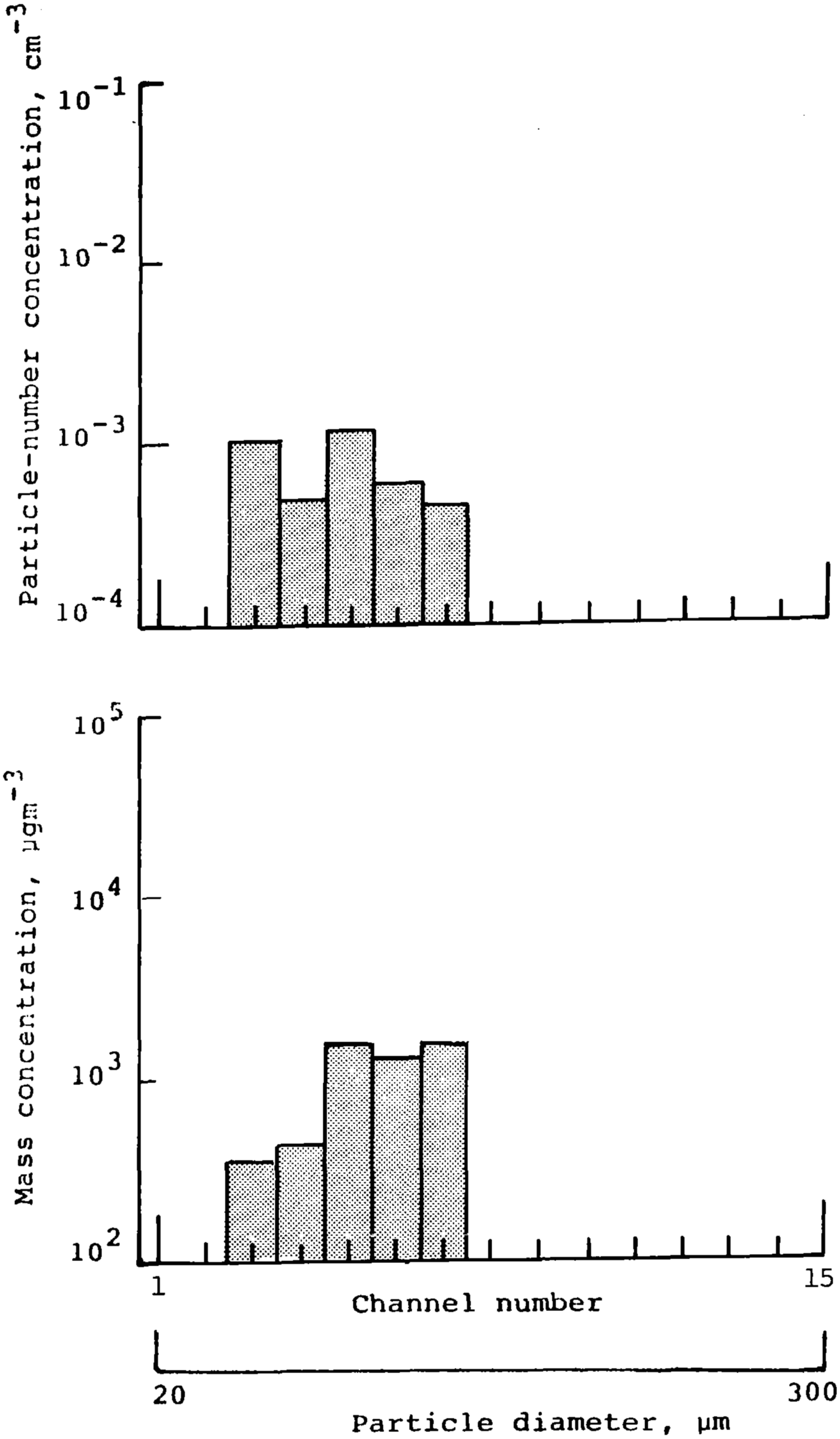
(c) Pass 3.

Figure 5.- Continued.



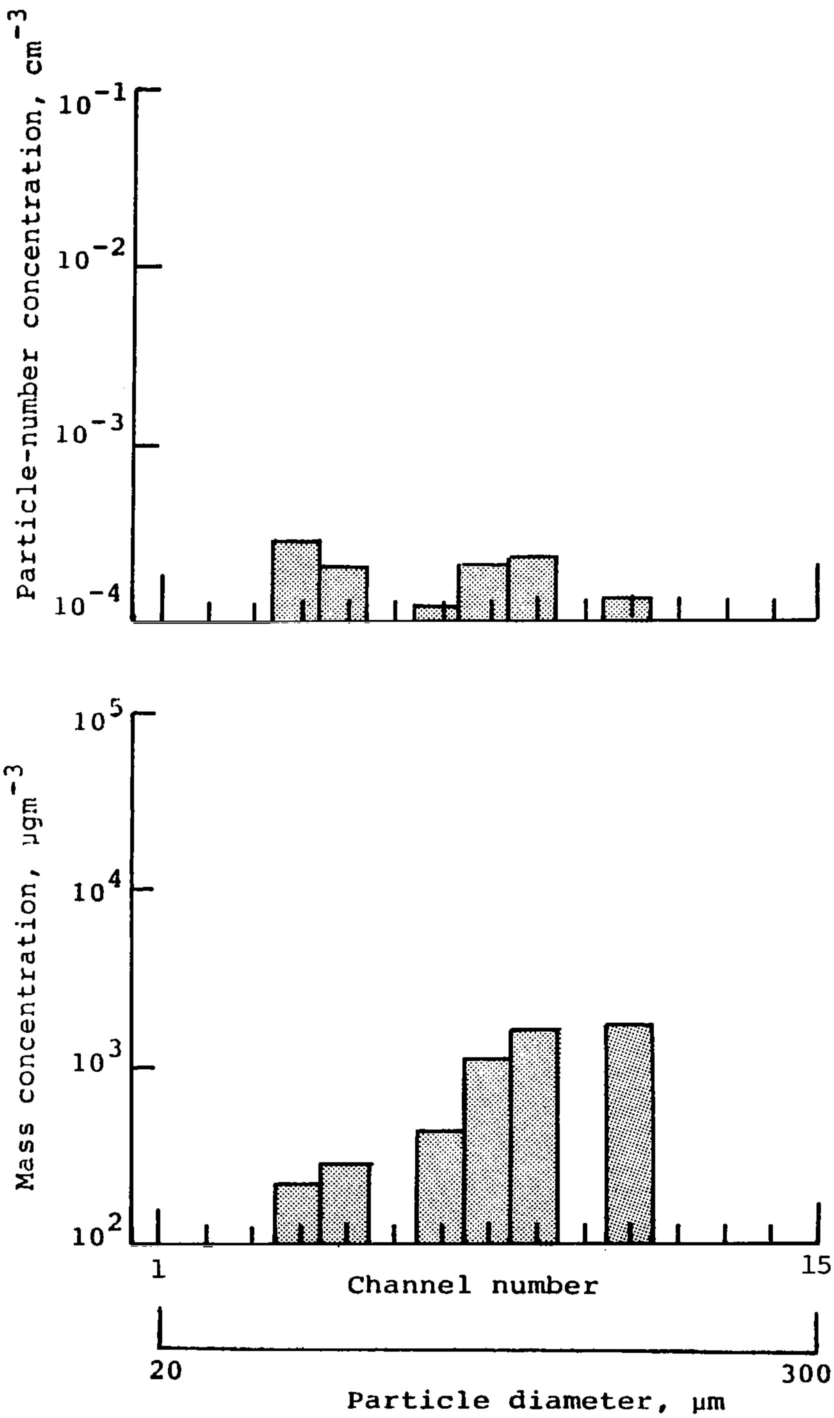
(d) Pass 4.

Figure 5.- Continued.



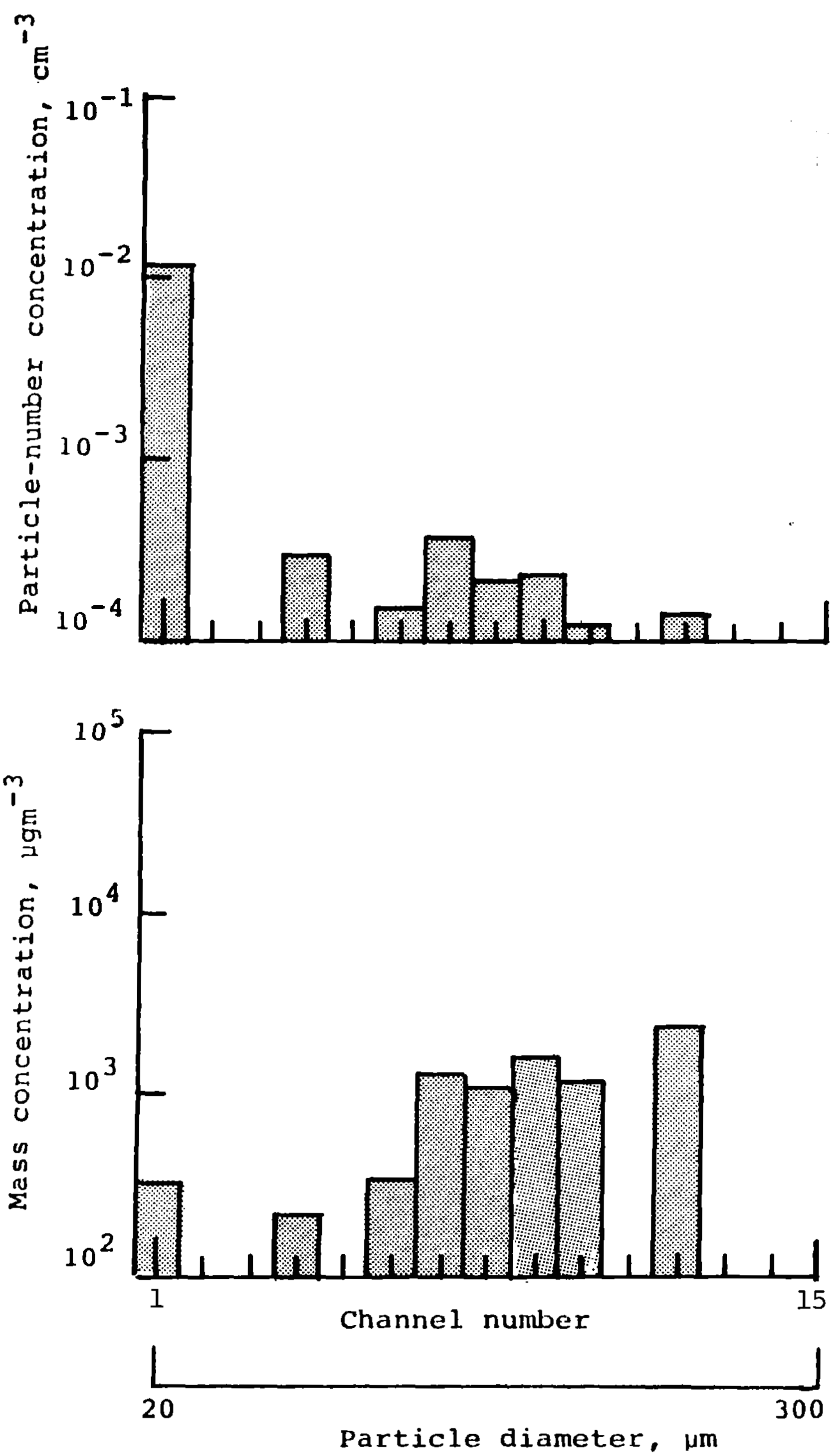
(e) Pass 5.

Figure 5.- Continued.



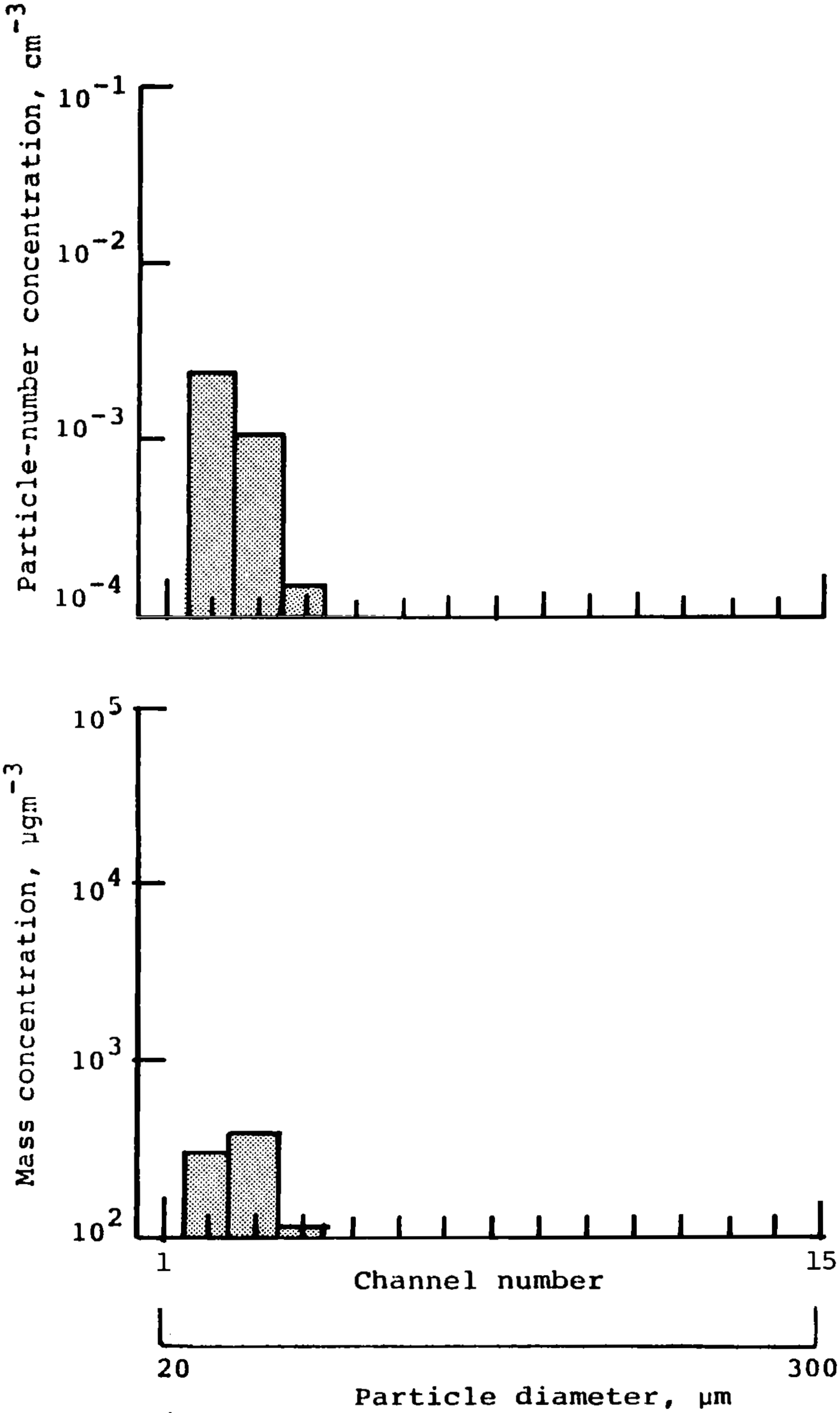
(f) Pass 6.

Figure 5.- Continued.



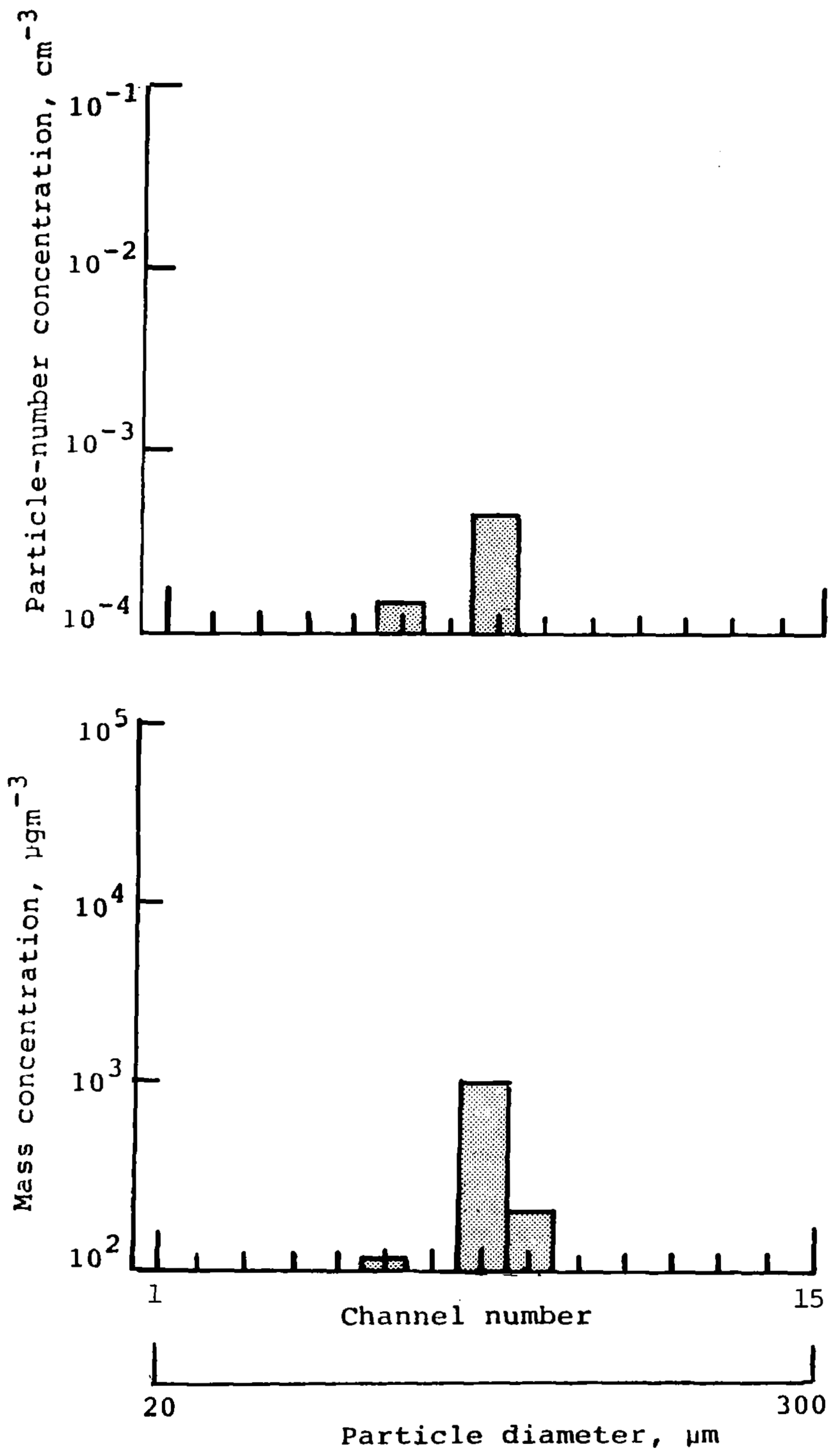
(g) Pass 7.

Figure 5.- Continued.



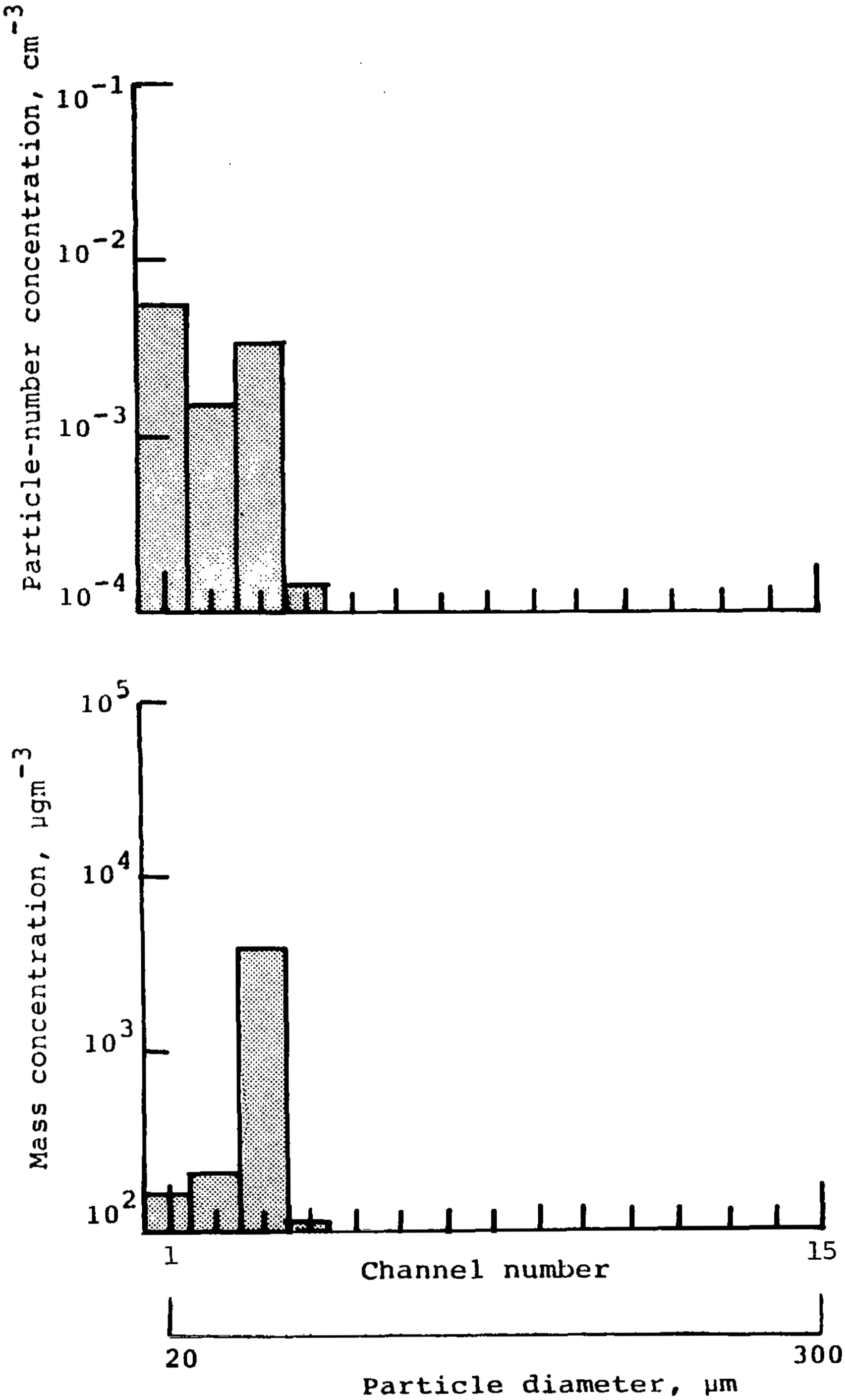
(h) Pass 8.

Figure 5.- Continued.



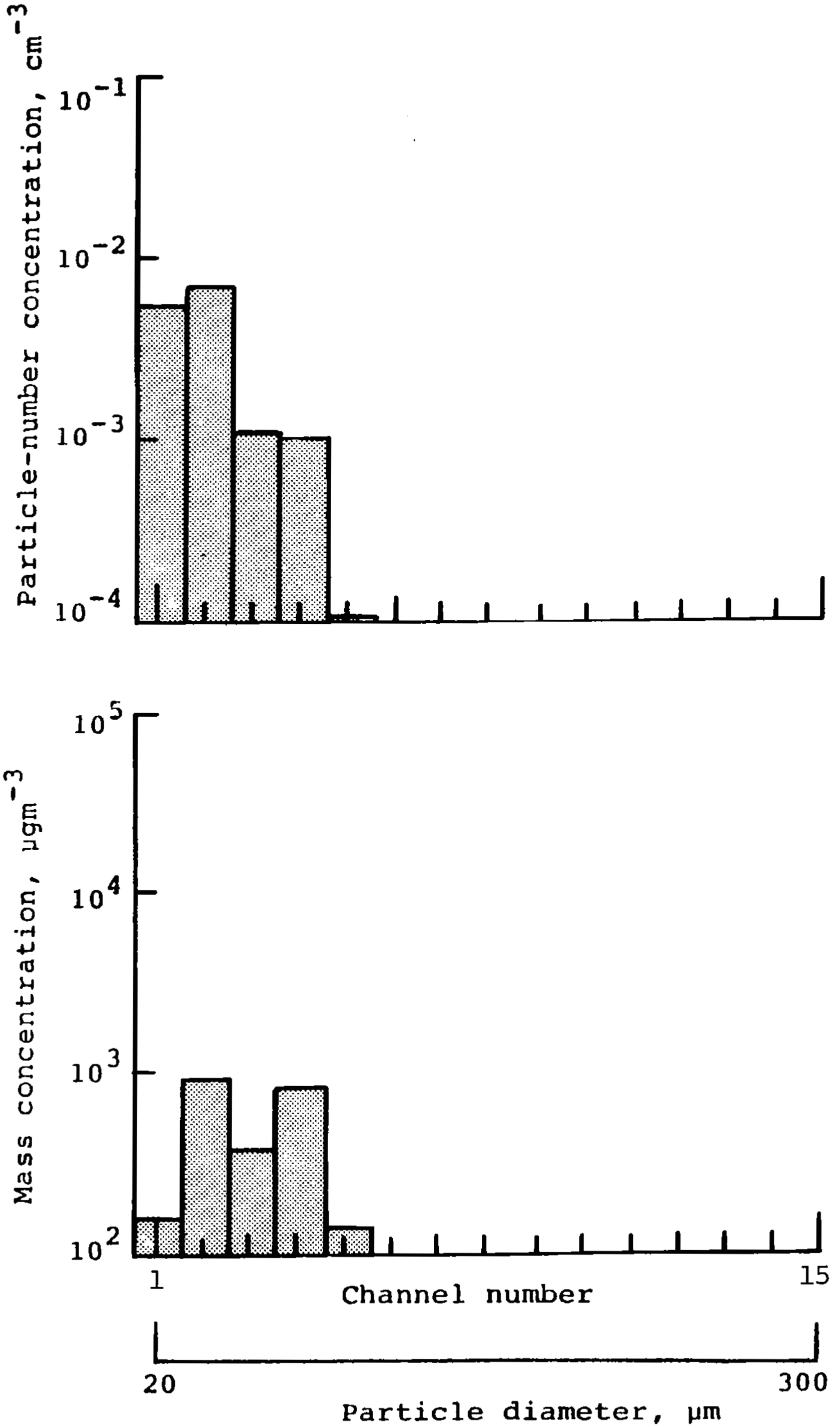
(i) Pass 10.

Figure 5.- Continued.



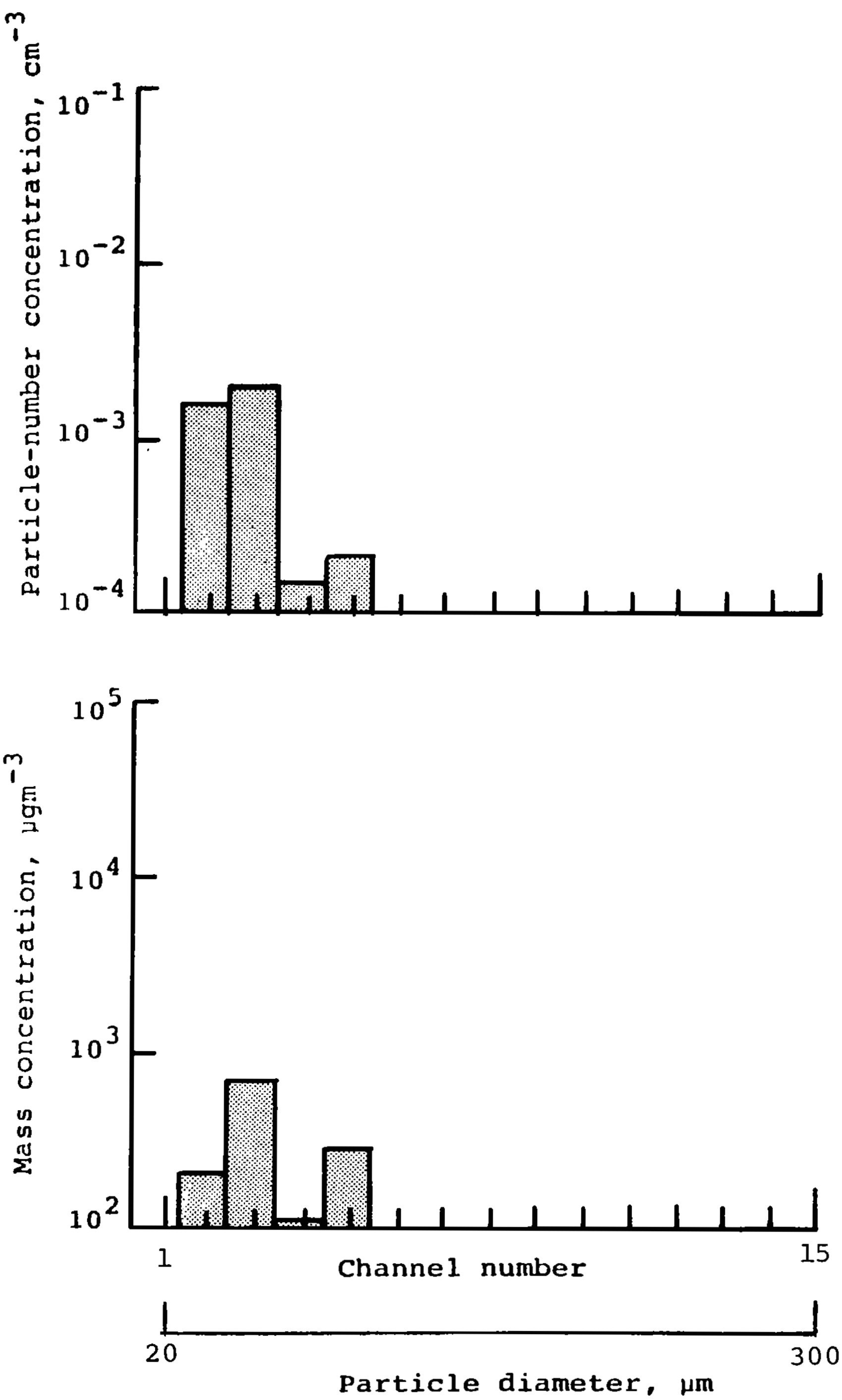
(j) Pass 11.

Figure 5.- Continued.



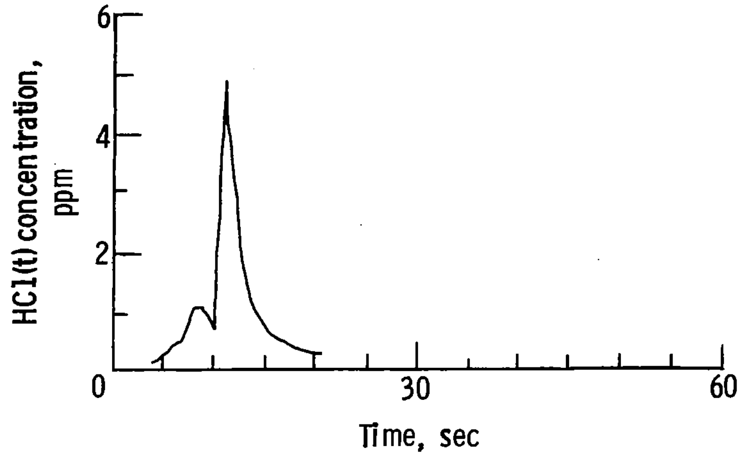
(k) Pass 12.

Figure 5.- Continued.

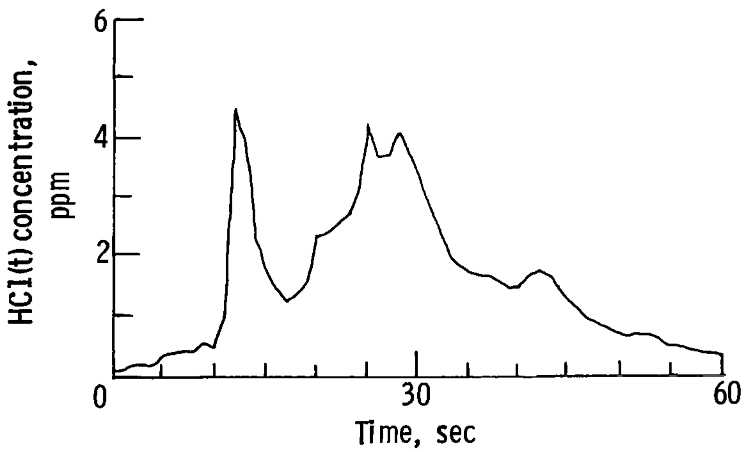


(l) Pass 13.

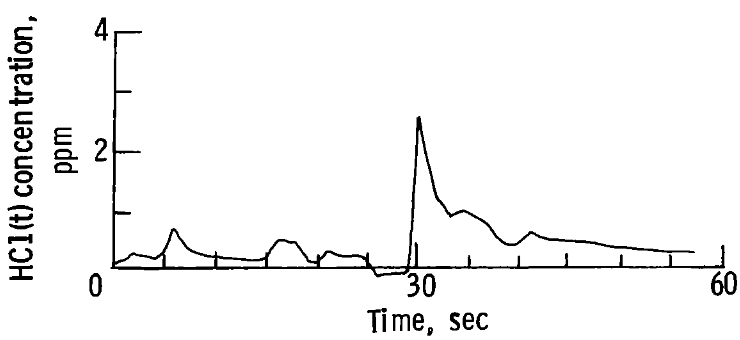
Figure 5.- Concluded.



(a) Pass 1; t_0 = 151 500 Z.

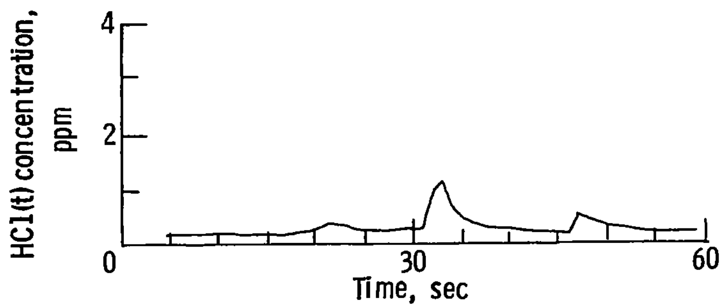


(b) Pass 2; t_0 = 151 735 Z.

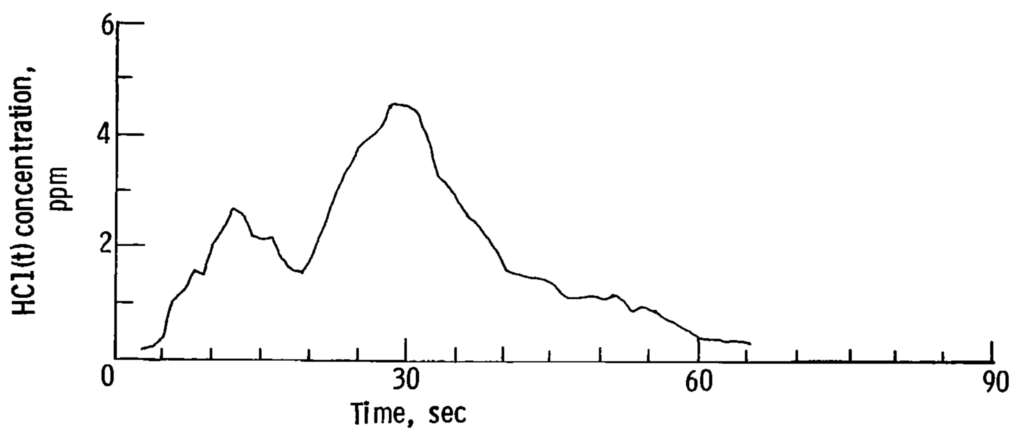


(c) Pass 3; t_0 = 152 030 Z.

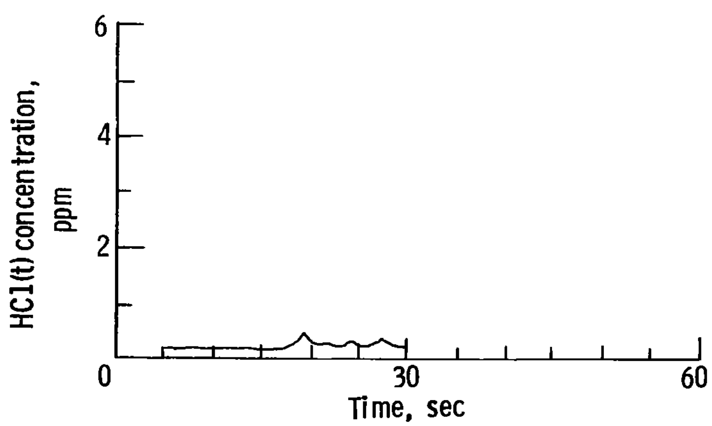
Figure 6.- Total HCl concentration plotted against time for passes 1 through 31. The times for t_0 may not agree from instrument to instrument for the same pass. No data were obtained for passes 13 and 19 because the instrument was not in the sensing mode.



(d) Pass 4; t_0 = 152 230 Z.

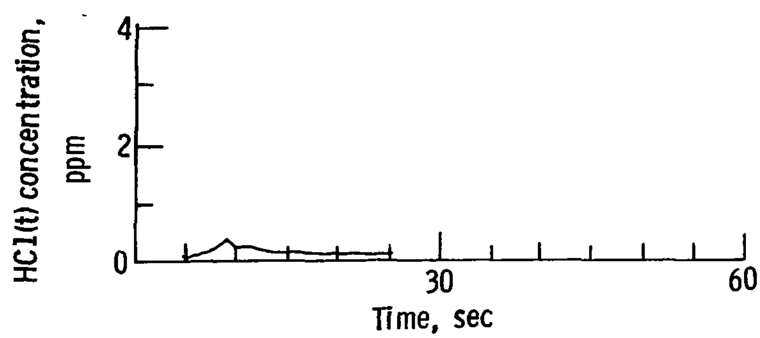


(e) Pass 5; t_0 = 152 555 Z.

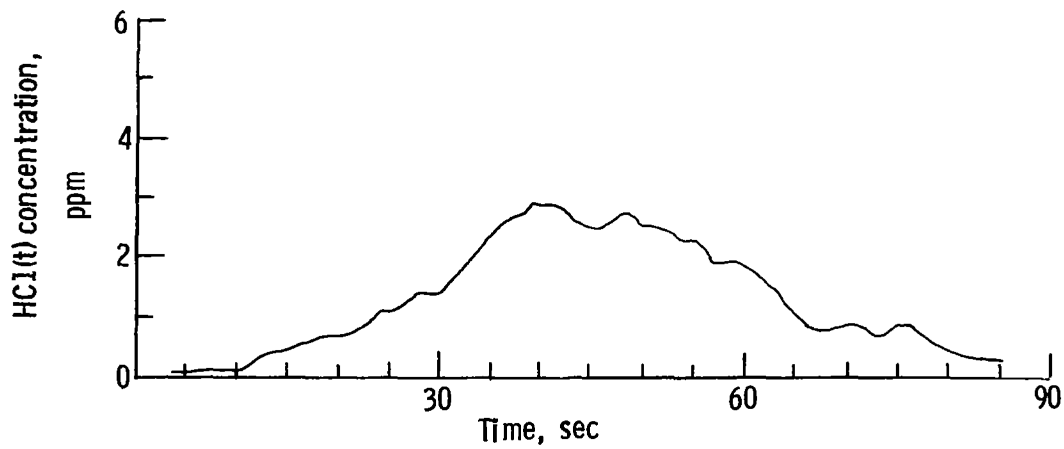


(f) Pass 6; t_0 = 152 915 Z.

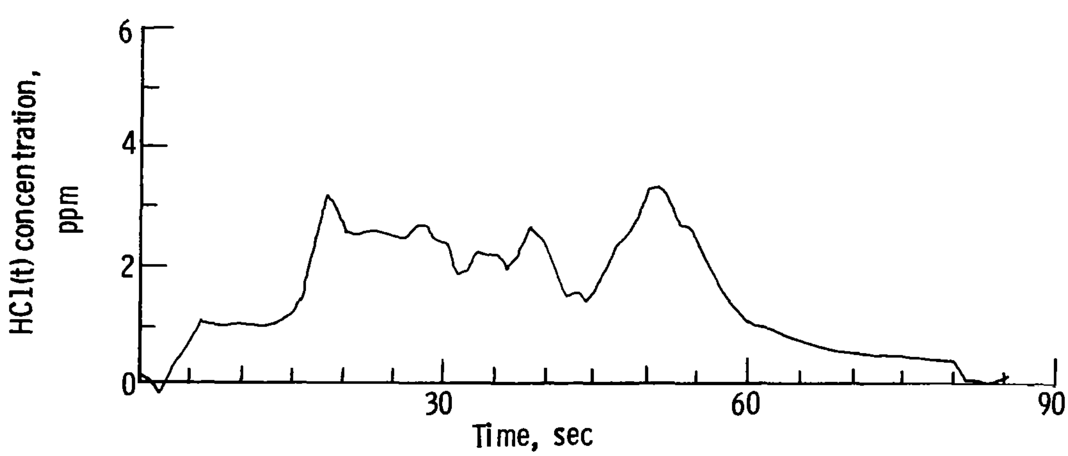
Figure 6.- Continued.



(g) Pass 7; t_0 = 153 125 Z.

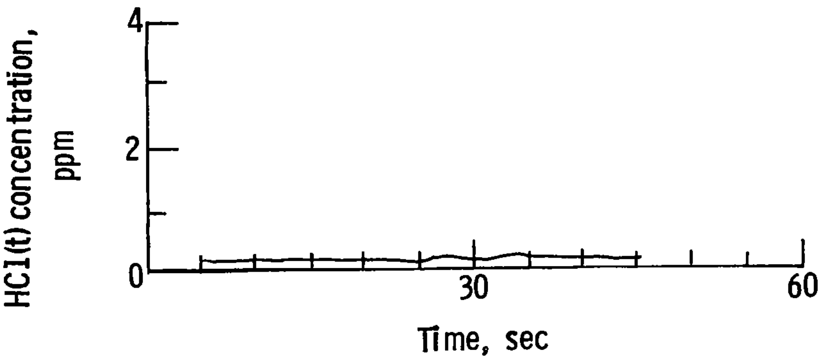


(h) Pass 8; t_0 = 153 500 Z.

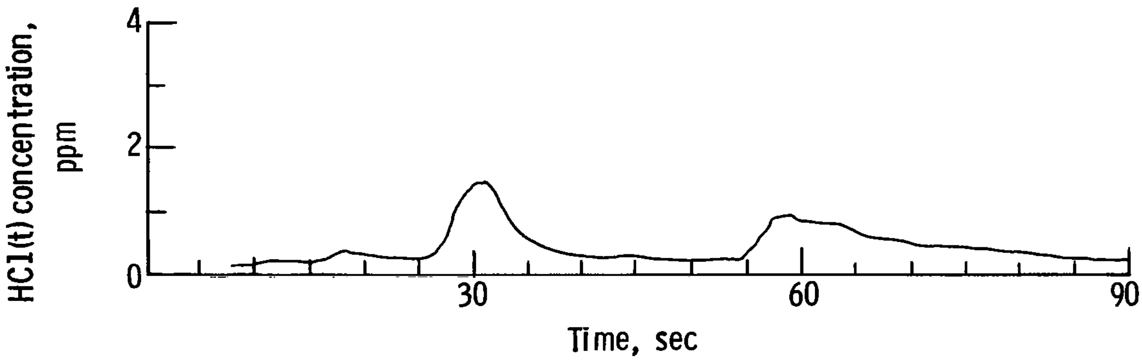


(i) Pass 9; t_0 = 153 730 Z.

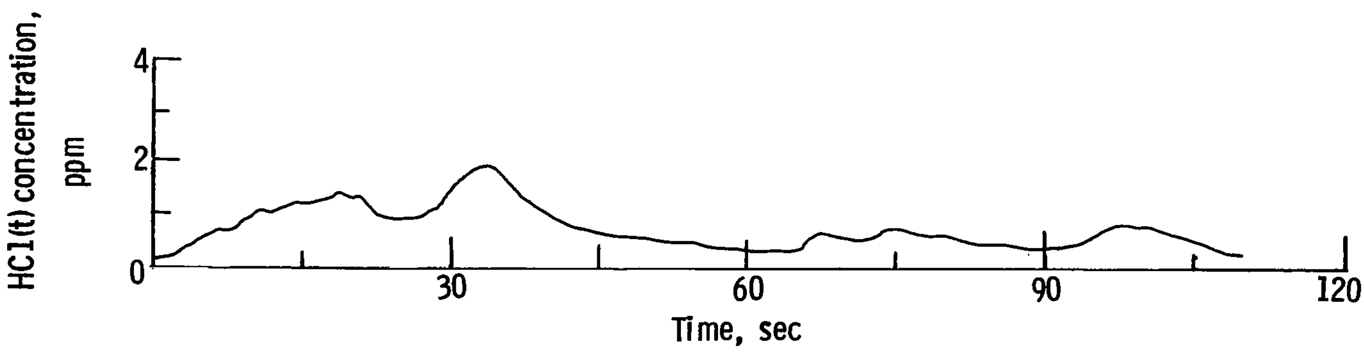
Figure 6.- Continued.



(j) Pass 10; t_0 = 154 055 Z.

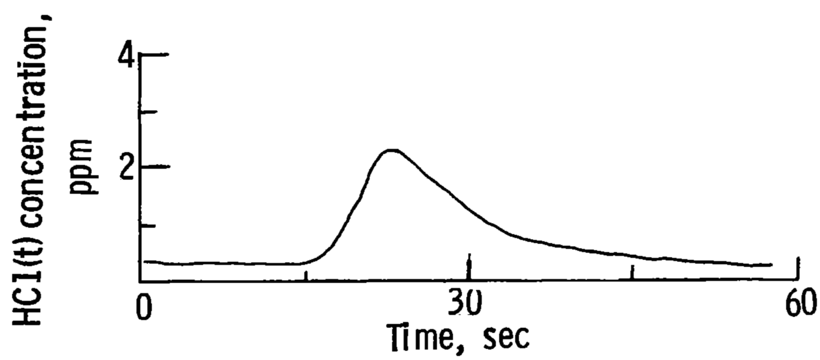


(k) Pass 11; t_0 = 154 300 Z.

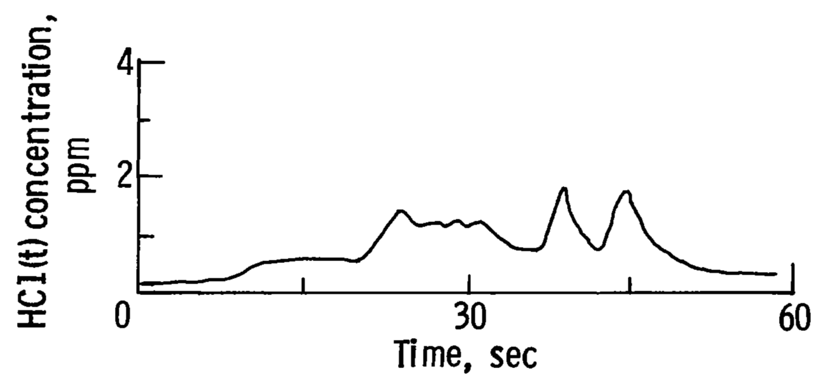


(l) Pass 12; t_0 = 154 545 Z.

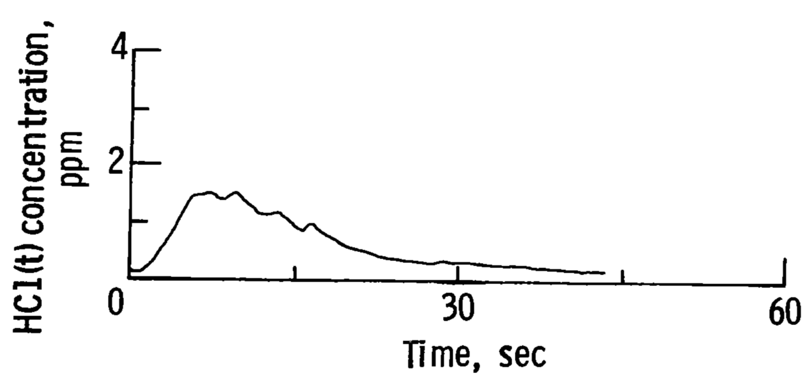
Figure 6.- Continued.



(m) Pass 14; t_0 = 155 000 Z.

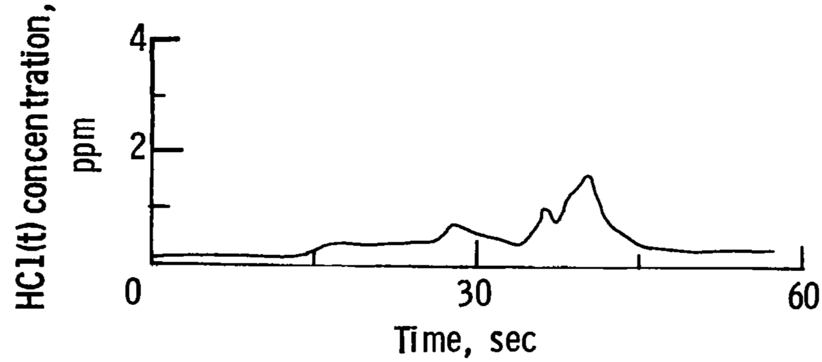


(n) Pass 15; t_0 = 155 222 Z.

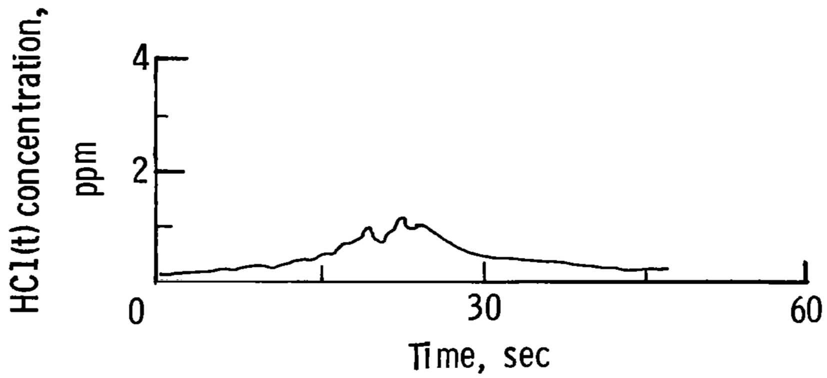


(o) Pass 16; t_0 = 155 545 Z.

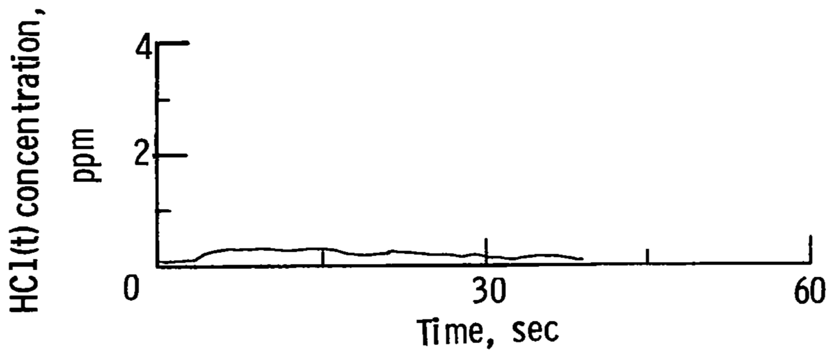
Figure 6.- Continued.



(p) Pass 17; t_0 = 155 730 Z.

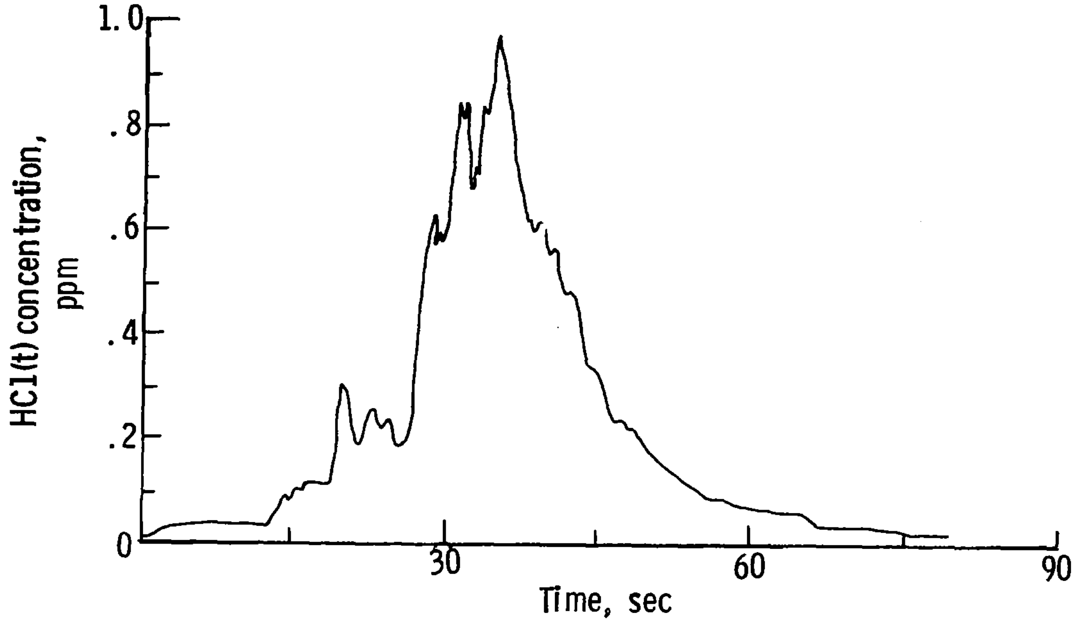


(q) Pass 18; t_0 = 160 115 Z.

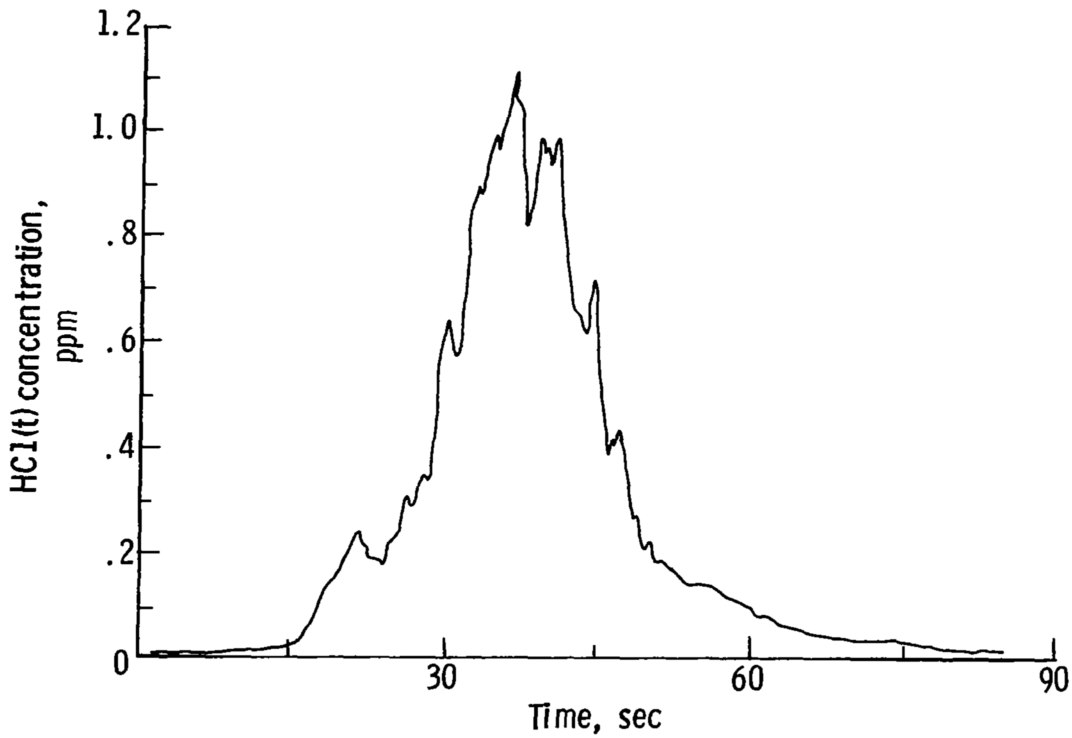


(r) Pass 20; t_0 = 160 630 Z.

Figure 6.- Continued.

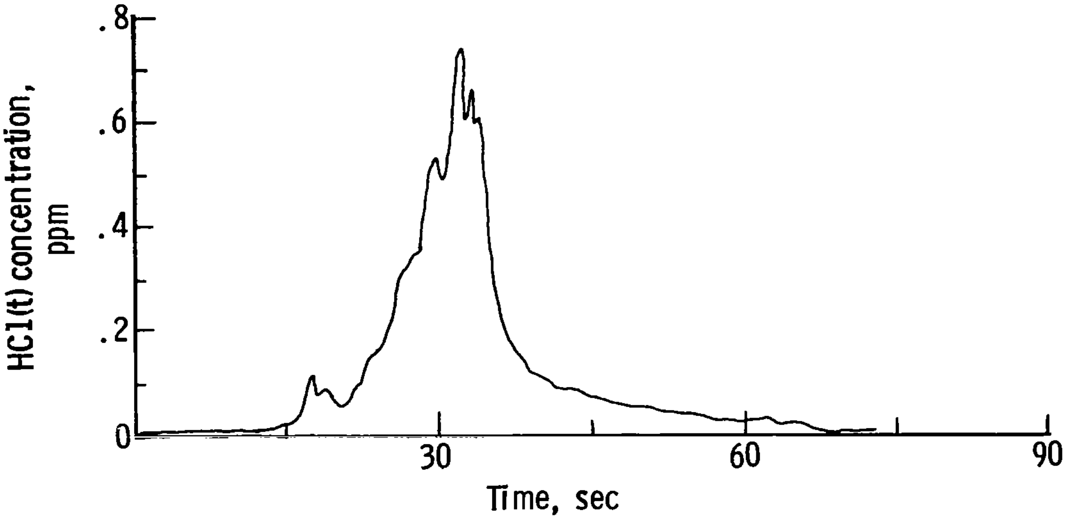


(s) Pass 21; t_0 = 161 000 Z.

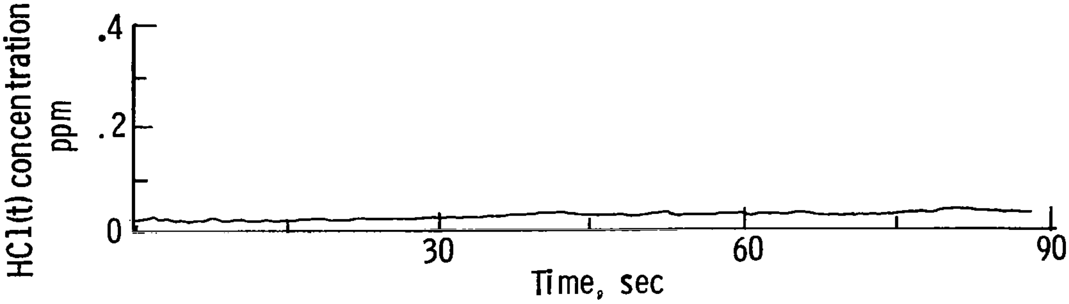


(t) Pass 22; t_0 = 161 230 Z.

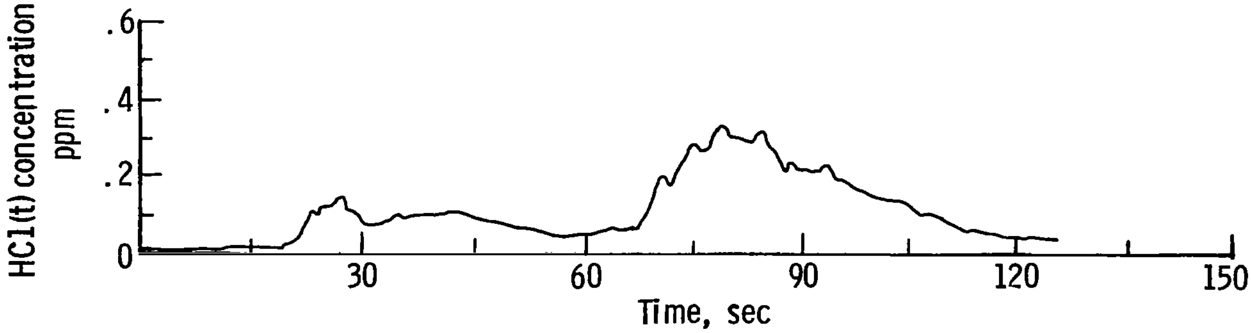
Figure 6.- Continued.



(u) Pass 23; t_0 = 161 630 Z.

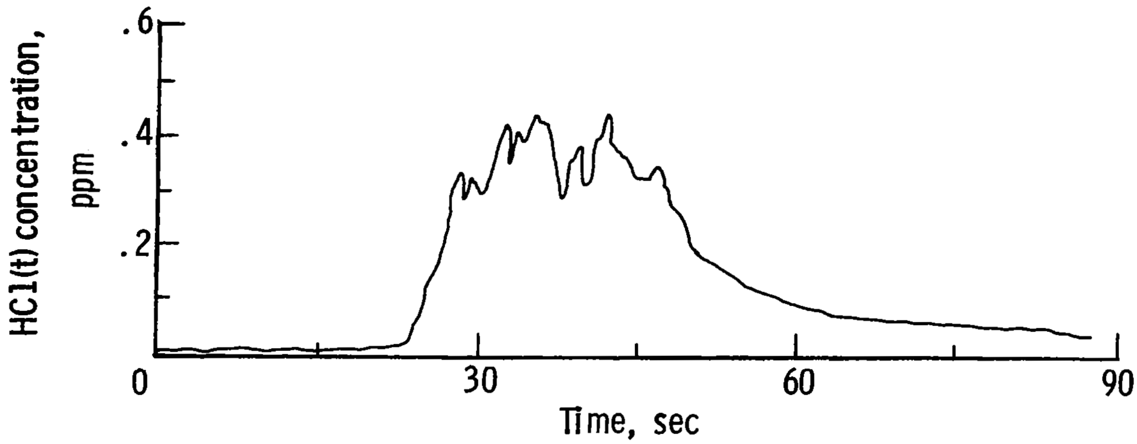


(v) Pass 24; t_0 = 162 530 Z.

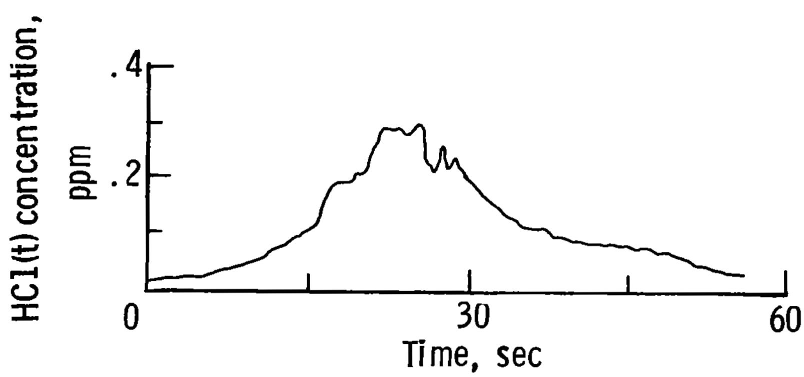


(w) Pass 25; t_0 = 163 330 Z.

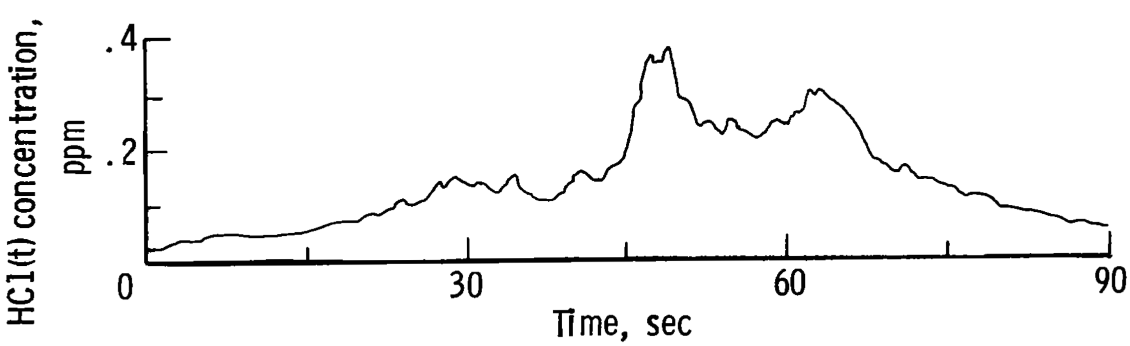
Figure 6.- Continued.



(x) Pass 26; t_0 = 163 930 Z.

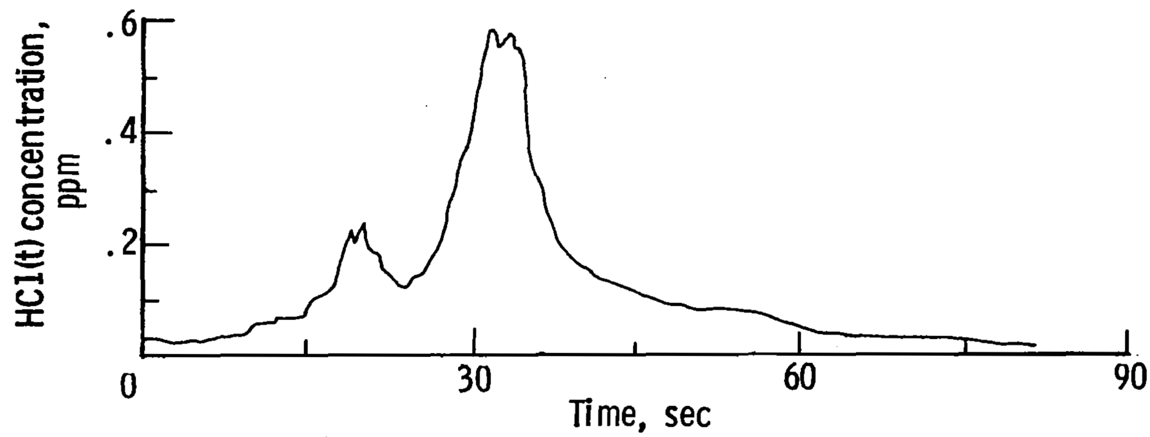


(y) Pass 27; t_0 = 164 200 Z.

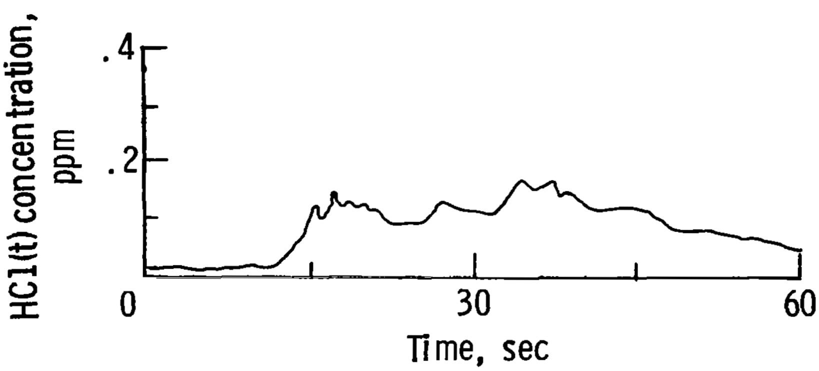


(z) Pass 28; t_0 = 164 330 Z.

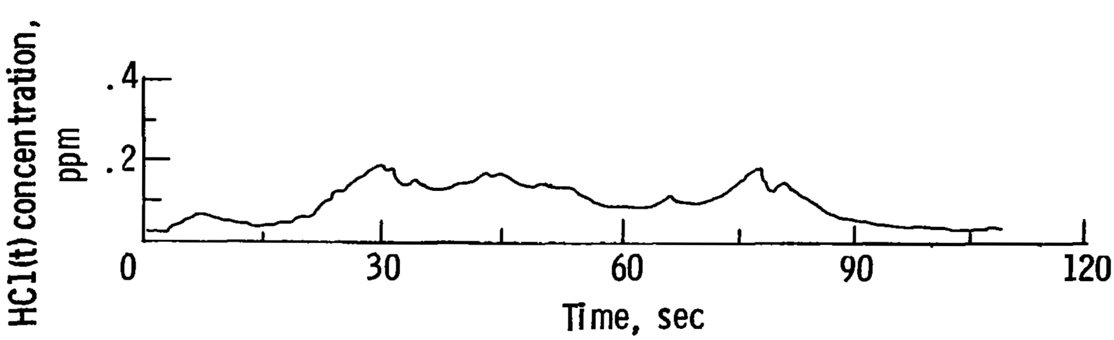
Figure 6.- Continued.



(aa) Pass 29; t_0 = 164 630 Z.

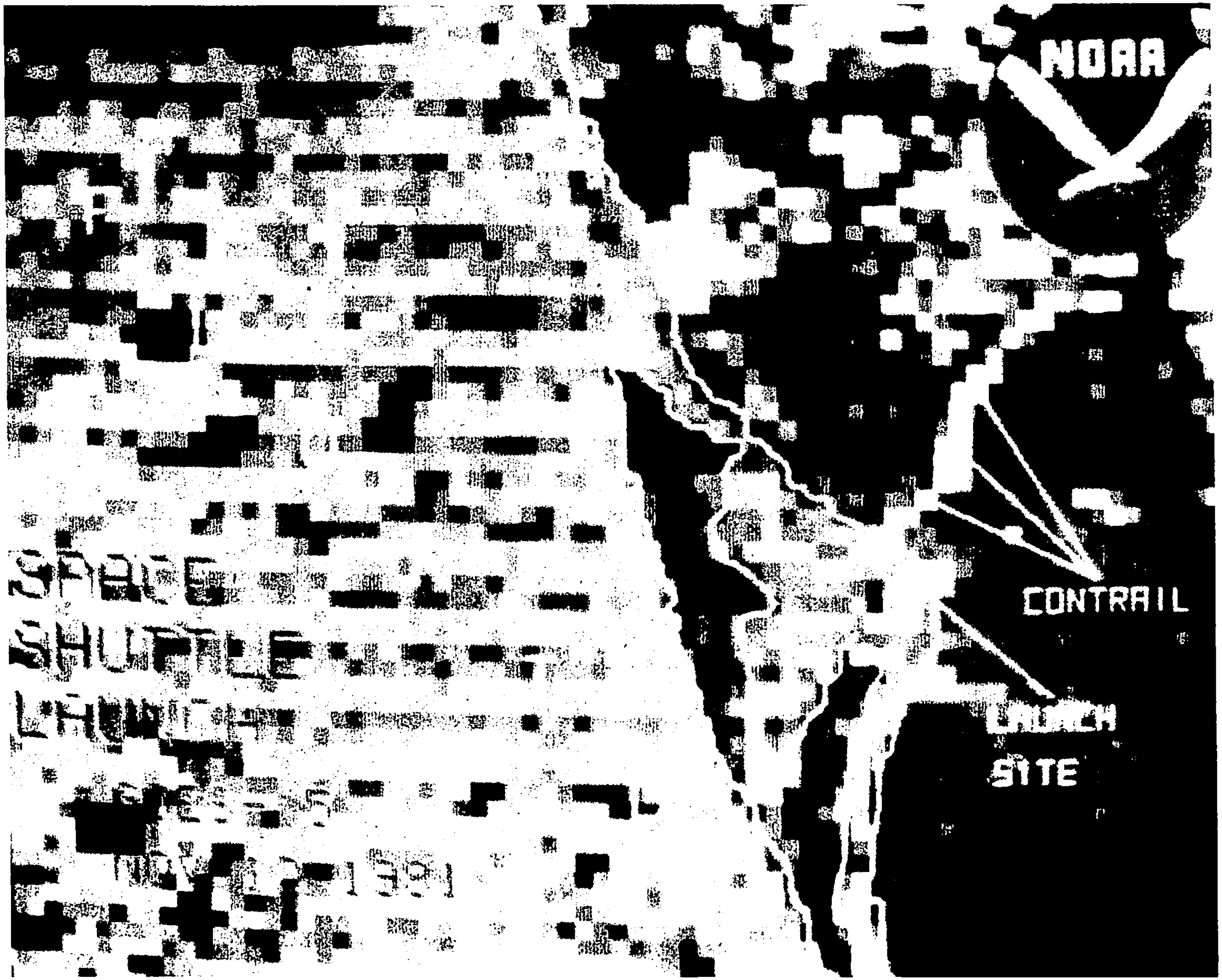


(bb) Pass 30; t_0 = 164 900 Z.



(cc) Pass 31; t_0 = 165 515 Z.

Figure 6.- Concluded.



L-83-154

Figure 7.- GOES satellite image showing STS-2 launch.

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4. Title and Subtitle AIRBORNE MEASUREMENTS OF LAUNCH VEHICLE EFFLUENT OF STS-2 LAUNCH ON NOVEMBER 12, 1981, AT CAPE CANAVERAL, FLORIDA		5. Report Date February 1984
		6. Performing Organization Code 925-23-20-03
7. Author(s) George L. Maddrea, Jr., Gerald L. Gregory, Daniel I. Sebacher, and David C. Woods		8. Performing Organization Report No. L-15715
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9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		11. Contract or Grant No.
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12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The second Space Shuttle (STS-2) was launched from the John F. Kennedy Space Center at 1010 EST on November 12, 1981. An instrumented light airplane was used to measure the emitted concentrations of Shuttle exhaust products produced during launch. The airplane accomplished 31 passes through and under the exhaust cloud in the 1 hr 45 min immediately following the launch. Measurements included the following: (1) particulate data in the form of a light scattering coefficient obtained from an integrating nephelometer, (2) particulate concentrations and mass concentrations obtained from a spectrometer probe, (3) gaseous HCl and total HCl concentrations obtained from a gas-filter-correlation instrument and a chemiluminescent instrument, respectively, and (4) outside-air temperature and dew-point temperature. These data are presented along with time, altitude, and position for each cloud pass. These data are within the range of values observed during similar measurements made during the first Space Shuttle launch on April 12, 1981.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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